Parity-Violating Asymmetry in $\vec{\mathbf{n}} + \mathbf{p} \to \mathbf{d} + \gamma$

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P-23

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The NPDGamma Experiment at Los Alamos NATIONAL LABORATORY

LANSCE is the only facility worldwide that can host this nuclear physics experiment.

NPDGamma is under construction and will begin data collection in 2003.

Measurement of the Parity-Violating Gamma Asymmetry A_γ in the Capture of Polarized Cold Neutrons by Para-Hydrogen, $\vec{n} + p \to d + \gamma$

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Outline

- What is NPDGamma measuring?
  Theory and some history

- Experimental apparatus

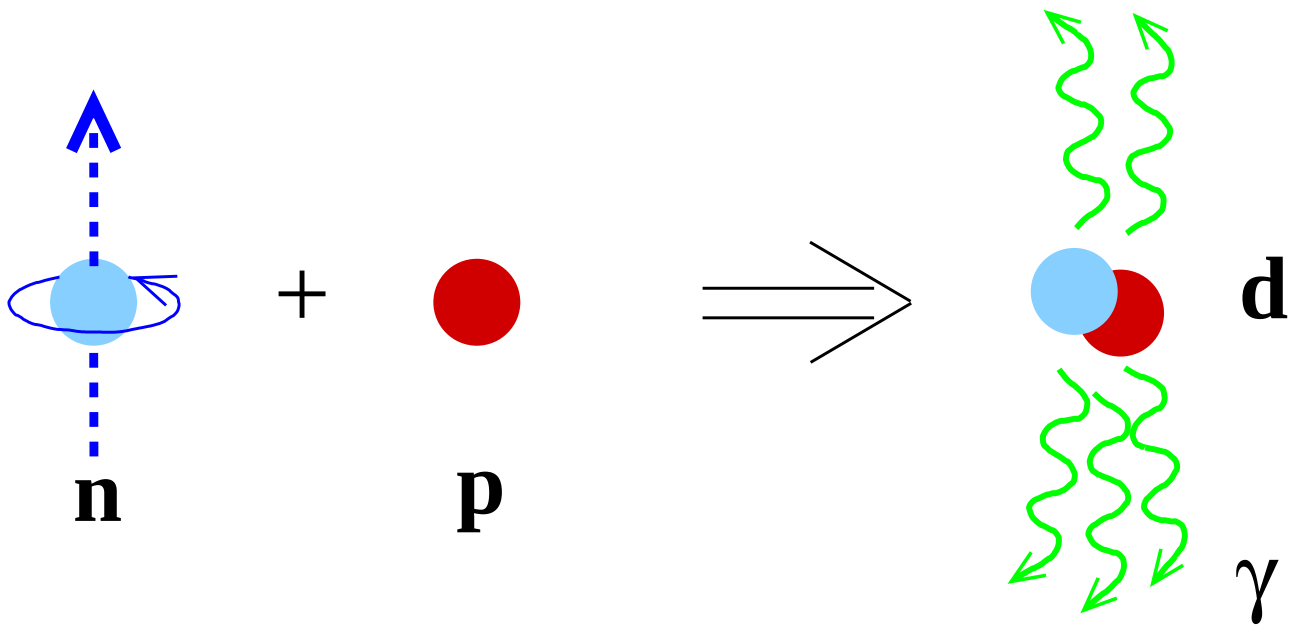
- Potential systematic errors

- Test runs with small scale apparatus &
  PV (n,γ) measurements on nuclear targets

- Status & schedule

$\vec{n} + p \to d + \gamma$ (2.2 MeV)

NPDGamma will measure A_γ, the parity-violating asymmetry in the distribution of emitted γ's



If the up/down γ rates differ, parity is violated (PV $\longrightarrow$ signature of the weak interaction)

Expected asymmetry $\approx -5 \times 10^{-8}$

Goal experimental error: 0.5×10^{-8}

Low-energy PV N-N potential contains coupling constants for meson exchange (π, ρ, ω).
A_γ is a clean measurement of H_π^1: $A_\gamma \approx -0.045 H_\pi^1$

What is NPDGamma measuring?

The laws of physics describe four interactions:

gravity

electromagnetism

strong force

weak force

The strong force binds hadrons together, and is the primary interaction between protons and neutrons.

The weak interaction between hadrons
(i.e. protons and neutrons)
is not well-measured or understood.

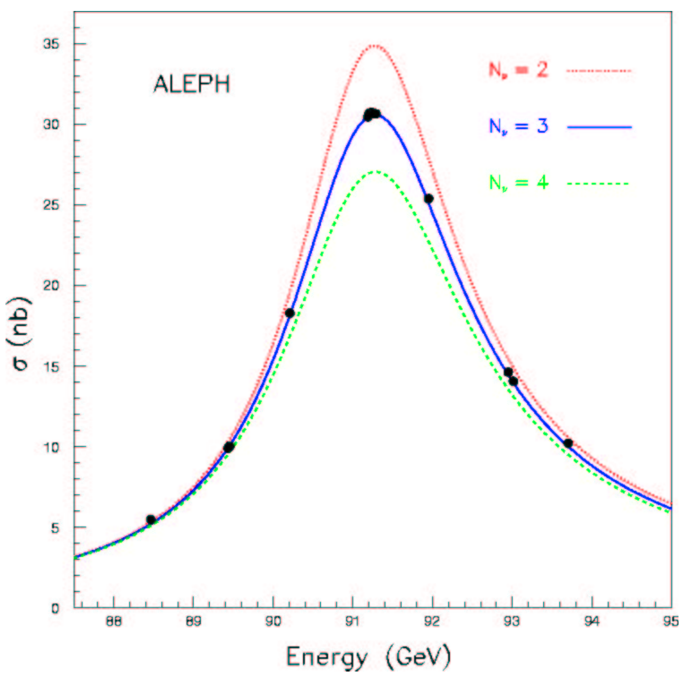
Weak Interaction

Standard model of electroweak interactions
has been extensively studied at colliders

precision measurements:

$$\begin{array}{lll} M_Z & = 91.1882 & \pm\ 0.0022\ \text{GeV} \\ M_W & = 80.419 & \pm\ 0.056\ \text{GeV} \end{array}$$

D.E. Groom *et al.* (Particle Data Group), Eur. Phys. Jour. **C15**, 1 (2000)



`http://alephwww.cern.ch`

well-understood how quarks
and leptons interact weakly
($W^{\pm}$ and Z exchange)

Categories of Weak Interactions

At low energies, consider the weak interaction as a point interaction of two currents.

Weak current-current Hamiltonian:

$$H = \frac{G_F}{\sqrt{2}}(J^\dagger J + J J^\dagger)$$

The weak current J_μ has leptonic and hadronic contributions, so weak interactions of three types occur.

- Leptonic: $\mu \to e^- + \nu_\mu \overline{\nu}_e$
- Semi-leptonic: $n \to p e^- \overline{\nu}_e$
- Nonleptonic: $K \to \pi\pi$

Nonleptonic weak interactions are most apparent in quark flavor-changing processes.

NPDGamma will study the flavor-conserving nonleptonic (i.e. hadronic) weak interaction.

Experiments to study the hadronic weak interaction necessarily involve strongly interacting hadrons.

Weak interactions in strongly interacting systems are not well understood.

e.g. The $\Delta I = 1/2$ rule:

$$\Gamma(K_s^0 \to \pi^0 \pi^0) \gg \Gamma(K^+ \to \pi^+ \pi^0)$$

Weak decay processes can be greatly affected by the strong interaction.

How to study the hadronic weak interaction?

To see its sometimes very small effects, a powerful technique is to use parity violation.

force	strong	weak
strength	$\sim 10^6$	1
parity?	conserved	violated

(Necessary to observe $\Delta s = 0$, nonleptonic weak interactions.)

(Brief)
History of Parity Violation

The possibility of PV in the weak interaction was first suggested by T. D. Lee and C. N. Yang.
[Phys. Rev. **104** (1956) 254.]

First seen experimentally by C. S. Wu, *et al.* in asymmetry of β emission from polarized ^{60}Co.
[Phys. Rev. **105** (1957) 1413.]

Parity violation in nuclear transitions first seen by V. M. Lobashov, *et al.* in circular polarization of the 482 keV γ ray from ^{181}Ta: $P_\gamma = -6 \pm 1 \times 10^{-6}$.
[Phys. Lett. **25B** (1967) 104.]

first measurement of hadronic PV

(many examples since in nuclear systems)

Range of Z, W^+, W^- bosons is 0.002 fm

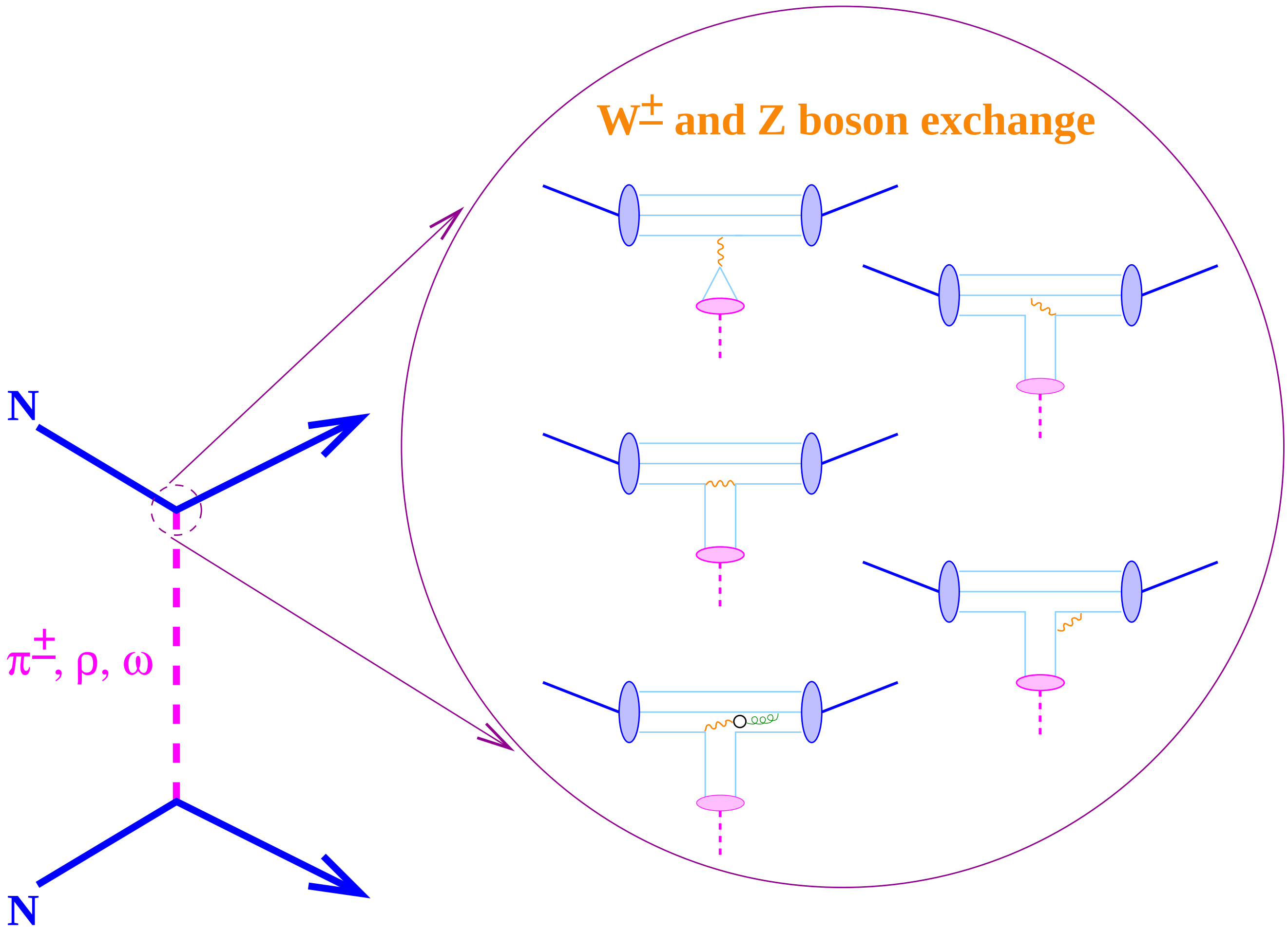
But nucleon interactions take place
on a scale of 1 fm (short range repulsion)

$\rightsquigarrow$ the weak force interaction between
nucleons and hadrons is a meson exchange

At low energies ($<$ 300 MeV)
mesons are the appropriate degree of freedom

Meson exchange potential model is a successful picture of strong interactions between nucleons (describes to a few % n-p/p-p scattering σ's)

N-N weak interaction modeled as meson exchange
with one strong PC vertex, one weak PV vertex

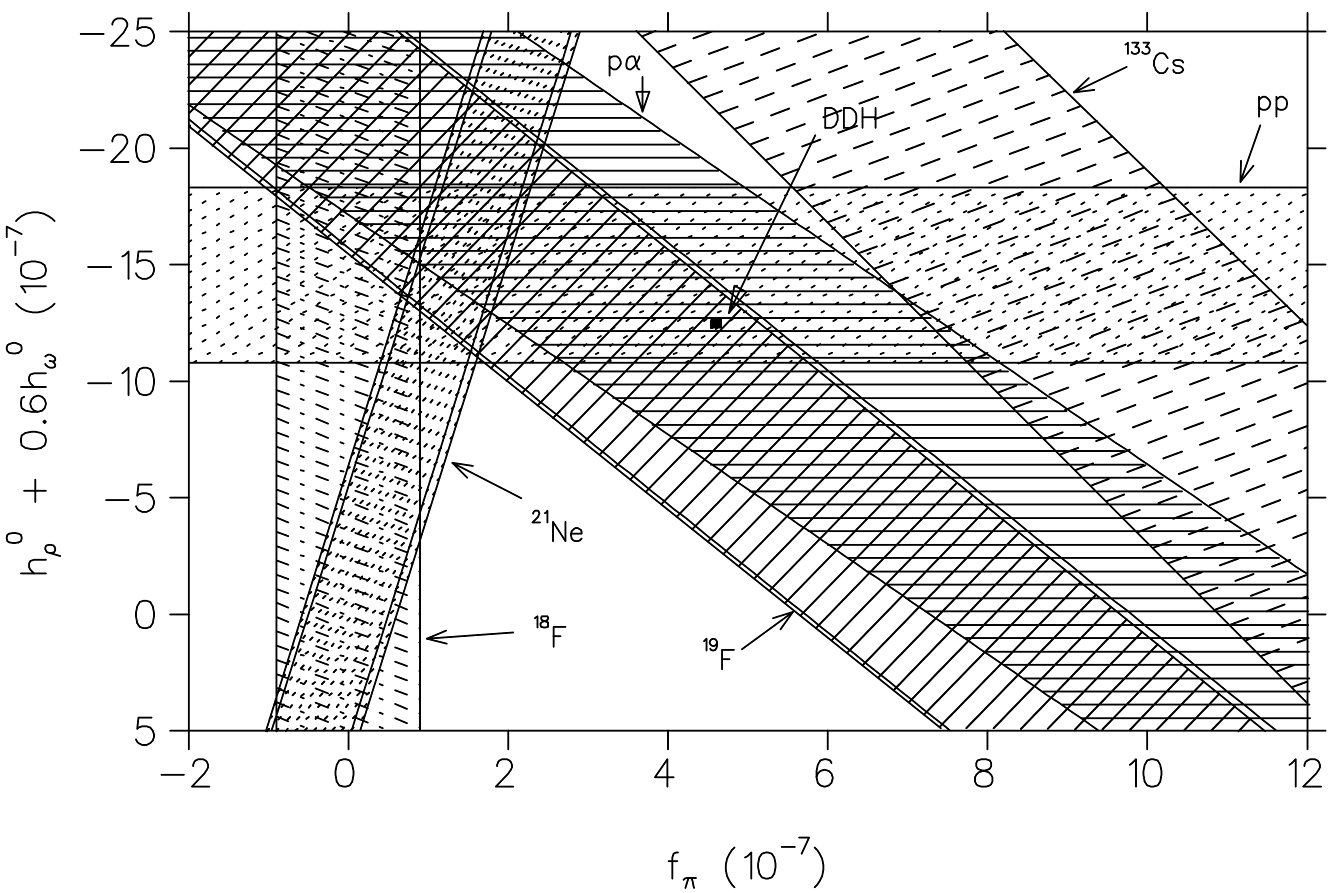


The weak PV couplings –

$$H_\pi^1,\ H_\rho^0,\ H_\rho^1,\ H_\rho^{1'},\ H_\rho^2,\ H_\omega^0,\ H_\omega^1$$

–measured in various combinations
by a variety of observables

Experimental Constraints on Weak N-N Couplings



[W. van Oers, Nucl. Phys. **A684** (2001) 266.]

N. B. $f_\pi = \frac{\sqrt{32}}{g_{\pi \mathrm{NN}}} \times H_\pi^1$

DDH

The benchmark theoretical calculations for nucleon-nucleon parity violation.

B. Desplanques, J. F. Donoghue, B. R. Holstein, Annals of Physics **124** (1980) 449.

DDH estimated the weak PV couplings based on:

quark model
SU(6)$_w$ symmetry
hyperon nonleptonic decays

Status of N-N Observables

A_z^{pp}(45 MeV) $\approx$

$$-0.053\left(H_\rho^0 + H_\rho^2/\sqrt{6}\right) - 0.016\left(H_\omega^0 + H_\omega^1\right)$$

PSI, Bonn, LANL

A_z^{pp}(221 MeV) $\approx$

$$0.028\left(H_\rho^0 + H_\rho^2/\sqrt{6}\right)$$

TRIUMF 497, 761

$A_\gamma^{np} \approx$

$$-0.045H_\pi^1$$

Under Construction — LANL

$P_\gamma^{np} \approx$

$$0.022H_\rho^0 + 0.043H_\rho^2/\sqrt{6}$$

Letter of Intent — JLab (LOI 00-002, PAC 17)

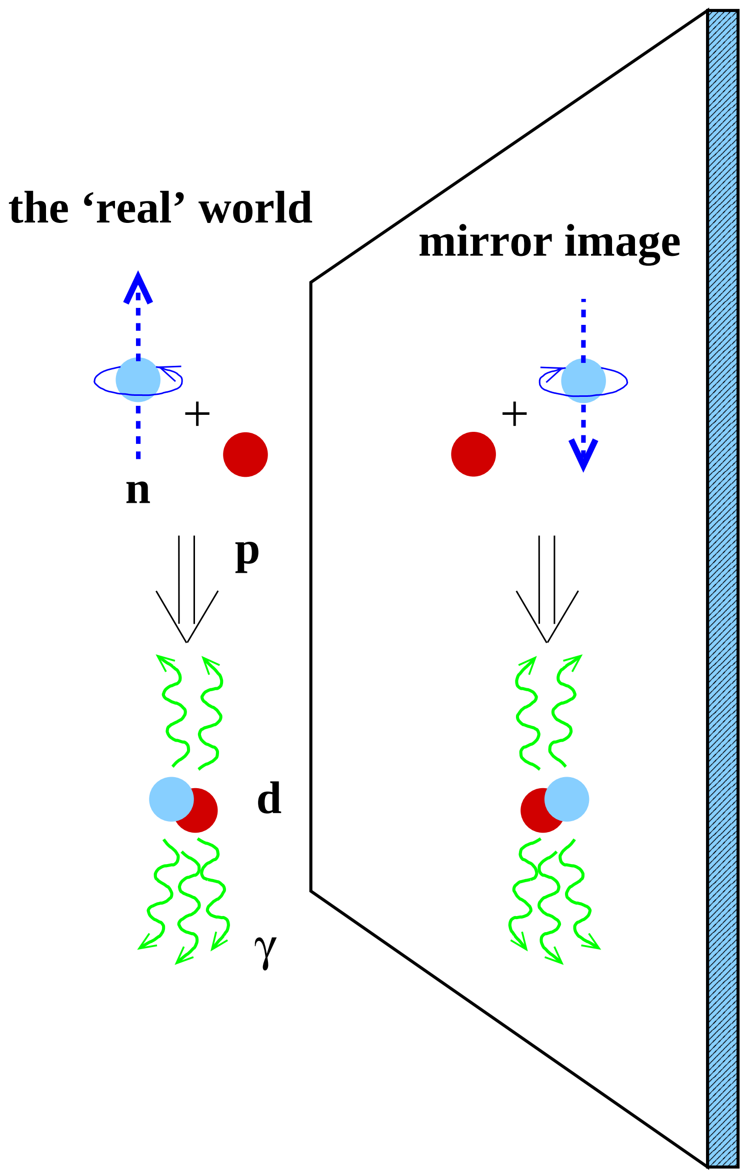
$\phi_{pnc}^{np} \approx$

$$-1.31H_\pi^1 - 0.23H_\rho^0 - 0.25H_\rho^2 - 0.23H_\omega^0$$

Under Development — NIST, ILL

$\vec{n} + p \rightarrow d + \gamma$ (2.2 MeV)

NPDGamma will measure A_γ, the parity-violating directional asymmetry in the distribution of γ's emitted in capture of polarized cold n by para-H_2



If the up/down γ rates differ, parity is violated (PV $\longrightarrow$ signature of the weak interaction)

Expected asymmetry $\approx -5 \times 10^{-8}$
Goal experimental error: 0.5×10^{-8}

Why is there parity violation in $\vec{n} + p \to d + \gamma$?

The weak force allows an interference between S and P states, which are states of opposite parity, in the capture of the neutron by the proton. (An interference between M1 and E1 amplitudes.)

The expected PV asymmetry is small

estimated size $G_F \times k_F^2 \approx 5 \times 10^{-7}$

Experimentally:
measure asymmetry between up and down γ rates

$$A_\gamma^{np} \approx -0.045 H_\pi^1$$

Clean interpretation in terms of only one coupling constant. (Rare and fortunate.)

A_γ in $\vec{n} + p \to d + \gamma$ is a measure of the:

- $\Delta s = 0$
- $\Delta I = 1$
- neutral current

weak hadronic interaction.

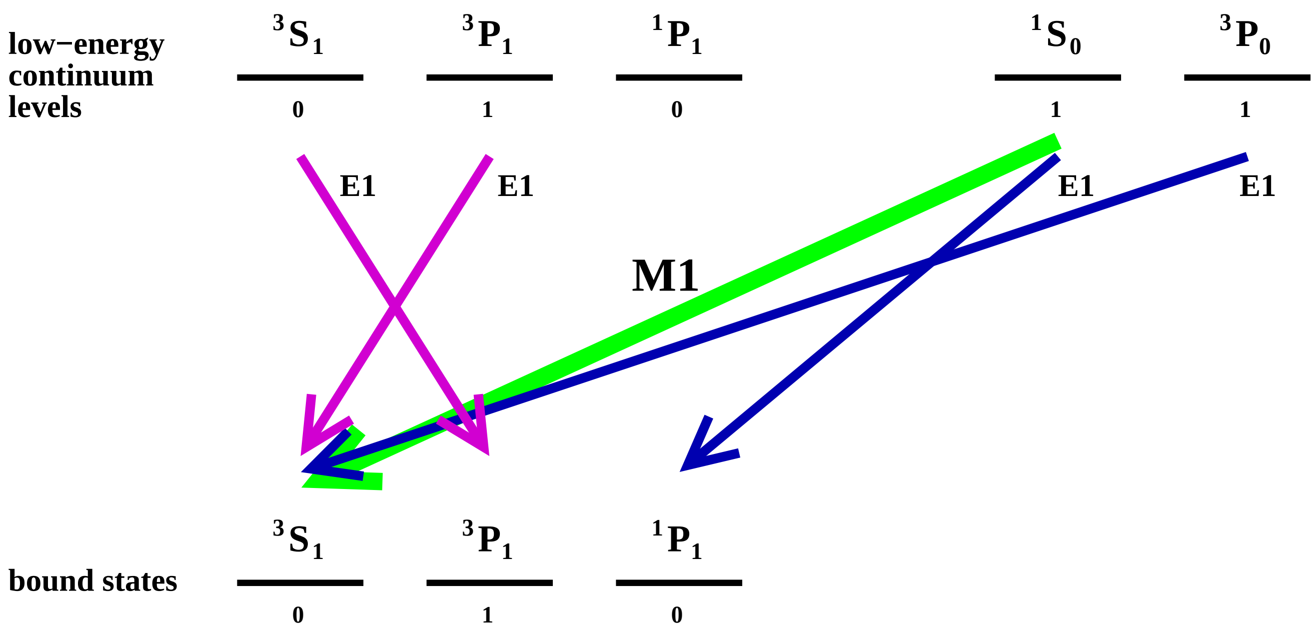
The longest range, most important weak N-N coupling is that to the pion:

$$H_\pi^1$$

which is $\Delta I = 1$. So A_γ measures H_π^1.

(CP invariance forbids exchange of neutral spinless mesons between on-shell nucleons.)

n − p system: $\frac{^{2S+1}L_J}{\text{isospin}}$



Capture is M1: $^1S_0$ to spin-1 deuteron $^3S_1$ (ignore D-state contribution)

Parity violation arises from mixing of P states and interference of the E1 transitions.

A_γ cannot come from J=0 capture states, so it must come from $^3S_1$ - $^3P_1$ mixing.

Therefore A_γ results from $\Delta I = 1$ terms in the weak Hamiltonian.

Why is $\Delta I = 1$ primarily neutral current?

$$H = \frac{G_F}{\sqrt{2}}(J_W^\dagger J_W + J_W J_W^\dagger + J_Z^\dagger J_Z)$$

Charged currents J_W have $\Delta I = \frac{1}{2}, 1$ components.

$J_W^\dagger J_W$: for $\Delta I = \frac{1}{2}$ currents $\rightarrow \Delta I = 1$
but this is Cabbibo suppressed (by $\sin^2 \theta_c$).

for $\Delta I = 1$ currents $\rightarrow \Delta I = 0, 1, 2$
but since the Hamiltonian is Hermitian, there are $\Delta I = 1$ components from both $J_W^\dagger J_W$ and $J_W J_W^\dagger$ which have opposite sign.

Thus, charged currents contribute to $\Delta I = 0, 2$ but not to $\Delta I = 1$.

Neutral currents J_Z have $\Delta I = 0, 1$ components.

$J_Z^\dagger J_Z$: $\Delta I = 0, 1, 2$

Neutral currents contribute to hadronic weak interactions of $\Delta I = 0, 1, 2$.

31. CLEBSCH-GORDAN COEFFICIENTS, SPHERICAL HARMONICS, AND d FUNCTIONS

Note: A square-root sign is to be understood over *every* coefficient, *e.g.*, for −8/15 read $-\sqrt{8/15}$.

Notation:

	J	J	...
	M	M	...
m_1 m_2			
m_1 m_2	Coefficients		
. .			

1/2×1/2

m_1	m_2	1, +1
+1/2	+1/2	1

m_1	m_2	1, 0	0, 0
+1/2	−1/2	1/2	1/2
−1/2	+1/2	1/2	−1/2

m_1	m_2	1, −1
−1/2	−1/2	1

1×1/2

m_1	m_2	3/2, +3/2
+1	+1/2	1

m_1	m_2	3/2, +1/2	1/2, +1/2
+1	−1/2	1/3	2/3
0	+1/2	2/3	−1/3

m_1	m_2	3/2, −1/2	1/2, −1/2
0	−1/2	2/3	1/3
−1	+1/2	1/3	−2/3

m_1	m_2	3/2, −3/2
−1	−1/2	1

2×1

m_1	m_2	3, +3
+2	+1	1

m_1	m_2	3, +2	2, +2
+2	0	1/3	2/3
+1	+1	2/3	−1/3

m_1	m_2	3, +1	2, +1	1, +1
+2	−1	1/15	1/3	3/5
+1	0	8/15	1/6	−3/10
0	+1	6/15	−1/2	1/10

m_1	m_2	3, 0	2, 0	1, 0
+1	−1	1/5	1/2	3/10
0	0	3/5	0	−2/5
−1	+1	1/5	−1/2	3/10

m_1	m_2	3, −1	2, −1	1, −1
0	−1	6/15	1/2	1/10
−1	0	8/15	−1/6	−3/10
−2	+1	1/15	−1/3	3/5

m_1	m_2	3, −2	2, −2
−1	−1	2/3	1/3
−2	0	1/3	−2/3

m_1	m_2	3, −3
−2	−1	1

1×1

m_1	m_2	2, +2
+1	+1	1

m_1	m_2	2, +1	1, +1
+1	0	1/2	1/2
0	+1	1/2	−1/2

m_1	m_2	2, 0	1, 0	0, 0
+1	−1	1/6	1/2	1/3
0	0	2/3	0	−1/3
−1	+1	1/6	−1/2	1/3

m_1	m_2	2, −1	1, −1
0	−1	1/2	1/2
−1	0	1/2	−1/2

m_1	m_2	2, −2
−1	−1	1

$$Y_1^0 = \sqrt{\frac{3}{4\pi}}\cos\theta$$

$$Y_1^1 = -\sqrt{\frac{3}{8\pi}}\sin\theta\, e^{i\phi}$$

$$Y_2^0 = \sqrt{\frac{5}{4\pi}}\Big(\frac{3}{2}\cos^2\theta - \frac{1}{2}\Big)$$

$$Y_2^1 = -\sqrt{\frac{15}{8\pi}}\sin\theta\cos\theta\, e^{i\phi}$$

$$Y_2^2 = \frac{1}{4}\sqrt{\frac{15}{2\pi}}\sin^2\theta\, e^{2i\phi}$$

2×1/2

m_1	m_2	5/2, +5/2
+2	1/2	1

m_1	m_2	5/2, +3/2	3/2, +3/2
+2	−1/2	1/5	4/5
+1	+1/2	4/5	−1/5

m_1	m_2	5/2, +1/2	3/2, +1/2
+1	−1/2	2/5	3/5
0	+1/2	3/5	−2/5

m_1	m_2	5/2, −1/2	3/2, −1/2
0	−1/2	3/5	2/5
−1	+1/2	2/5	−3/5

m_1	m_2	5/2, −3/2	3/2, −3/2
−1	−1/2	4/5	1/5
−2	+1/2	1/5	−4/5

m_1	m_2	5/2, −5/2
−2	−1/2	1

3/2×1/2

m_1	m_2	2, +2
+3/2	+1/2	1

m_1	m_2	2, +1	1, +1
+3/2	−1/2	1/4	3/4
+1/2	+1/2	3/4	−1/4

m_1	m_2	2, 0	1, 0
+1/2	−1/2	1/2	1/2
−1/2	+1/2	1/2	−1/2

m_1	m_2	2, −1	1, −1
−1/2	−1/2	3/4	1/4
−3/2	+1/2	1/4	−3/4

m_1	m_2	2, −2
−3/2	−1/2	1

3/2×1

m_1	m_2	5/2, +5/2
+3/2	+1	1

m_1	m_2	5/2, +3/2	3/2, +3/2
+3/2	0	2/5	3/5
+1/2	+1	3/5	−2/5

m_1	m_2	5/2, +1/2	3/2, +1/2	1/2, +1/2
+3/2	−1	1/10	2/5	1/2
+1/2	0	3/5	1/15	−1/3
−1/2	+1	3/10	−8/15	1/6

m_1	m_2	5/2, −1/2	3/2, −1/2	1/2, −1/2
+1/2	−1	3/10	8/15	1/6
−1/2	0	3/5	−1/15	−1/3
−3/2	+1	1/10	−2/5	1/2

m_1	m_2	5/2, −3/2	3/2, −3/2
−1/2	−1	3/5	2/5
−3/2	0	2/5	−3/5

m_1	m_2	5/2, −5/2
−3/2	−1	1

$$Y_\ell^{-m} = (-1)^m Y_\ell^{m*}$$

$$d^\ell_{m,0} = \sqrt{\frac{4\pi}{2\ell+1}}\, Y_\ell^m\, e^{-im\phi}$$

$$\langle j_1 j_2 m_1 m_2 | j_1 j_2 J M\rangle = (-1)^{J-j_1-j_2}\langle j_2 j_1 m_2 m_1 | j_2 j_1 J M\rangle$$

$$d^j_{m',m} = (-1)^{m-m'} d^j_{m,m'} = d^j_{-m,-m'}$$

3/2×3/2

m_1	m_2	3, +3
+3/2	+3/2	1

m_1	m_2	3, +2	2, +2
+3/2	+1/2	1/2	1/2
+1/2	+3/2	1/2	−1/2

m_1	m_2	3, +1	2, +1	1, +1
+3/2	−1/2	1/5	1/2	3/10
+1/2	+1/2	3/5	0	−2/5
−1/2	+3/2	1/5	−1/2	3/10

m_1	m_2	3, 0	2, 0	1, 0	0, 0
+3/2	−3/2	1/20	1/4	9/20	1/4
+1/2	−1/2	9/20	1/4	−1/20	−1/4
−1/2	+1/2	9/20	−1/4	−1/20	1/4
−3/2	+3/2	1/20	−1/4	9/20	−1/4

m_1	m_2	3, −1	2, −1	1, −1
+1/2	−3/2	1/5	1/2	3/10
−1/2	−1/2	3/5	0	−2/5
−3/2	+1/2	1/5	−1/2	3/10

m_1	m_2	3, −2	2, −2
−1/2	−3/2	1/2	1/2
−3/2	−1/2	1/2	−1/2

m_1	m_2	3, −3
−3/2	−3/2	1

$$d^1_{0,0} = \cos\theta \qquad d^{1/2}_{1/2,1/2} = \cos\frac{\theta}{2} \qquad d^{1/2}_{1/2,-1/2} = -\sin\frac{\theta}{2}$$

$$d^1_{1,1} = \frac{1+\cos\theta}{2} \qquad d^1_{1,0} = -\frac{\sin\theta}{\sqrt{2}} \qquad d^1_{1,-1} = \frac{1-\cos\theta}{2}$$

2×3/2

m_1	m_2	7/2, +7/2
+2	+3/2	1

m_1	m_2	7/2, +5/2	5/2, +5/2
+2	+1/2	3/7	4/7
+1	+3/2	4/7	−3/7

m_1	m_2	7/2, +3/2	5/2, +3/2	3/2, +3/2
+2	−1/2	1/7	16/35	2/5
+1	1/2	4/7	1/35	−2/5
0	3/2	2/7	−18/35	1/5

m_1	m_2	7/2, +1/2	5/2, +1/2	3/2, +1/2	1/2, +1/2
+2	−3/2	1/35	6/35	2/5	2/5
+1	−1/2	12/35	5/14	0	−3/10
0	1/2	18/35	−3/35	−1/5	1/5
−1	3/2	4/35	−27/70	2/5	−1/10

m_1	m_2	7/2, −1/2	5/2, −1/2	3/2, −1/2	1/2, −1/2
+1	−3/2	4/35	27/70	2/5	1/10
0	−1/2	18/35	3/35	−1/5	−1/5
−1	1/2	12/35	−5/14	0	3/10
−2	3/2	1/35	−6/35	2/5	−2/5

m_1	m_2	7/2, −3/2	5/2, −3/2	3/2, −3/2
0	−3/2	2/7	18/35	1/5
−1	−1/2	4/7	−1/35	−2/5
−2	1/2	1/7	−16/35	2/5

m_1	m_2	7/2, −5/2	5/2, −5/2
−1	−3/2	4/7	3/7
−2	−1/2	3/7	−4/7

m_1	m_2	7/2, −7/2
−2	−3/2	1

2×2

m_1	m_2	4, +4
+2	+2	1

m_1	m_2	4, +3	3, +3
+2	+1	1/2	1/2
+1	+2	1/2	−1/2

m_1	m_2	4, +2	3, +2	2, +2
+2	0	3/14	1/2	2/7
+1	1	4/7	0	−3/7
0	2	3/14	−1/2	2/7

m_1	m_2	4, +1	3, +1	2, +1	1, +1
+2	−1	1/14	3/10	3/7	1/5
+1	0	3/7	1/5	−1/14	−3/10
0	1	3/7	−1/5	−1/14	3/10
−1	2	1/14	−3/10	3/7	−1/5

m_1	m_2	4, 0	3, 0	2, 0	1, 0	0, 0
+2	−2	1/70	1/10	2/7	2/5	1/5
+1	−1	8/35	2/5	1/14	−1/10	−1/5
0	0	18/35	0	−2/7	0	1/5
−1	1	8/35	−2/5	1/14	1/10	−1/5
−2	2	1/70	−1/10	2/7	−2/5	1/5

m_1	m_2	4, −1	3, −1	2, −1	1, −1
+1	−2	1/14	3/10	3/7	1/5
0	−1	3/7	1/5	−1/14	−3/10
−1	0	3/7	−1/5	−1/14	3/10
−2	1	1/14	−3/10	3/7	−1/5

m_1	m_2	4, −2	3, −2	2, −2
0	−2	3/14	1/2	2/7
−1	−1	4/7	0	−3/7
−2	0	3/14	−1/2	2/7

m_1	m_2	4, −3	3, −3
−1	−2	1/2	1/2
−2	−1	1/2	−1/2

m_1	m_2	4, −4
−2	−2	1

$$d^{3/2}_{3/2,3/2} = \frac{1+\cos\theta}{2}\cos\frac{\theta}{2}$$

$$d^{3/2}_{3/2,1/2} = -\sqrt{3}\frac{1+\cos\theta}{2}\sin\frac{\theta}{2}$$

$$d^{3/2}_{3/2,-1/2} = \sqrt{3}\frac{1-\cos\theta}{2}\cos\frac{\theta}{2}$$

$$d^{3/2}_{3/2,-3/2} = -\frac{1-\cos\theta}{2}\sin\frac{\theta}{2}$$

$$d^{3/2}_{1/2,1/2} = \frac{3\cos\theta-1}{2}\cos\frac{\theta}{2}$$

$$d^{3/2}_{1/2,-1/2} = -\frac{3\cos\theta+1}{2}\sin\frac{\theta}{2}$$

$$d^2_{2,2} = \Big(\frac{1+\cos\theta}{2}\Big)^2$$

$$d^2_{2,1} = -\frac{1+\cos\theta}{2}\sin\theta$$

$$d^2_{2,0} = \frac{\sqrt{6}}{4}\sin^2\theta$$

$$d^2_{2,-1} = -\frac{1-\cos\theta}{2}\sin\theta$$

$$d^2_{2,-2} = \Big(\frac{1-\cos\theta}{2}\Big)^2$$

$$d^2_{1,1} = \frac{1+\cos\theta}{2}(2\cos\theta-1)$$

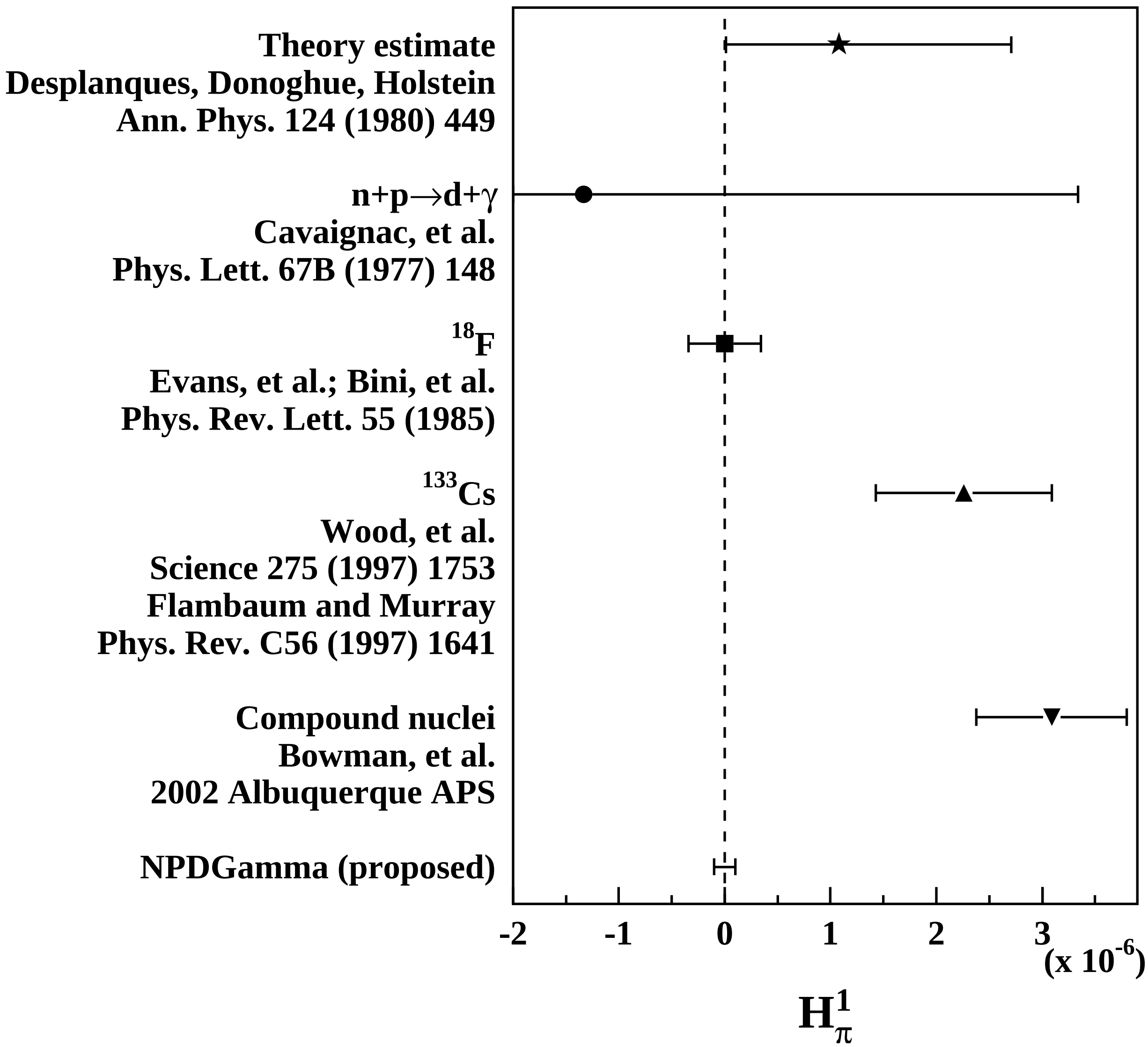
$$d^2_{1,0} = -\sqrt{\frac{3}{2}}\sin\theta\cos\theta$$

$$d^2_{1,-1} = \frac{1-\cos\theta}{2}(2\cos\theta+1)$$

$$d^2_{0,0} = \Big(\frac{3}{2}\cos^2\theta - \frac{1}{2}\Big)$$

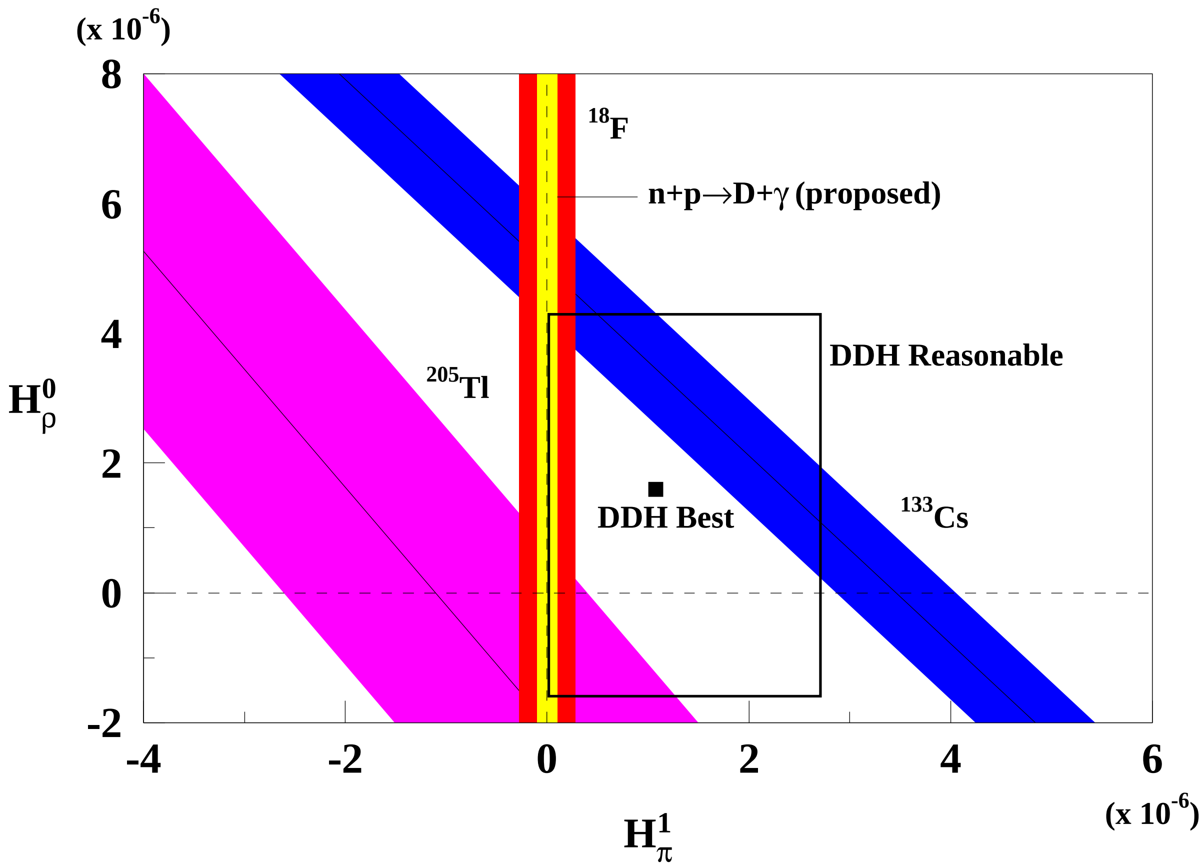
Figure 31.1: The sign convention is that of Wigner (*Group Theory*, Academic Press, New York, 1959), also used by Condon and Shortley (*The Theory of Atomic Spectra*, Cambridge Univ. Press, New York, 1953), Rose (*Elementary Theory of Angular Momentum*, Wiley, New York, 1957), and Cohen (*Tables of the Clebsch-Gordan Coefficients*, North American Rockwell Science Center, Thousand Oaks, Calif., 1974). The coefficients here have been calculated using computer programs written independently by Cohen and at LBNL.

A_γ is a clean measurement of H_π^1: $A_\gamma \approx -0.045 H_\pi^1$



NPDGamma will provide a measurement with improved statistical precision compared to ^{18}F results, with no uncertainties from many-body calculations or nuclear structure effects.

Weak Couplings from ^{18}F, ^{133}Cs, and ^{205}Tl



W.S. Wilburn and J.D. Bowman, Phys. Rev. **C57** (1998), 3425.

NPDGamma will provide a measurement with improved statistical precision compared to ^{18}F results, with no uncertainties from many-body calculations or nuclear structure effects

What does NPDGamma need?

- lots of polarized cold neutrons

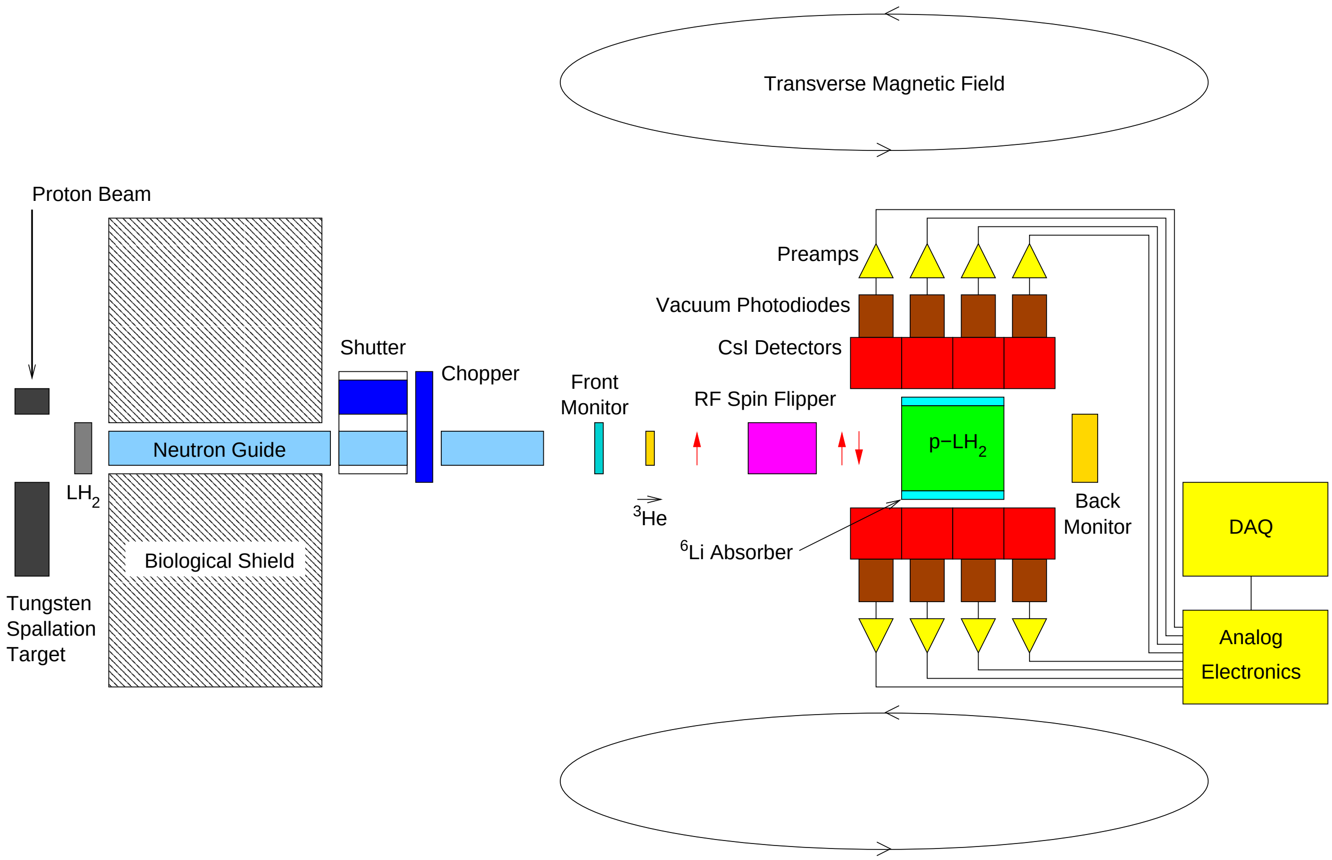
  &

  rapid reversal of neutron polarization

- protons

- γ detectors

NPDGamma Experimental Setup



NPDGamma is a fully funded experiment ($4.8M, primarily DOE)

Experiment: measure the directional asymmetry

$$A_\gamma$$

of 2.2 MeV γ-rays emitted upon polarized neutron capture in the para-hydrogen target.

NPDGamma Vital Statistics

LANSCE accelerator:

$\frac{1}{2}$ mile long, 80 kW, 800 MeV H^-

The LANSCE accelerator is the world's highest power linear proton accelerator.

PSR operates at 20 Hz, delivers up to 100 μA of protons to W spallation target at Lujan Center.

The peak neutron flux at the Lujan Center is the highest in the world.

---

neutron beam polarized by ^{3}He spin filter
neutron polarization: 0.50 $\rightarrow$ 0.95

FP12 peak flux: 6×10^7 n/ms (@ 8 meV = 3.2 Å)

event rate per 20 Hz pulse: 8×10^7

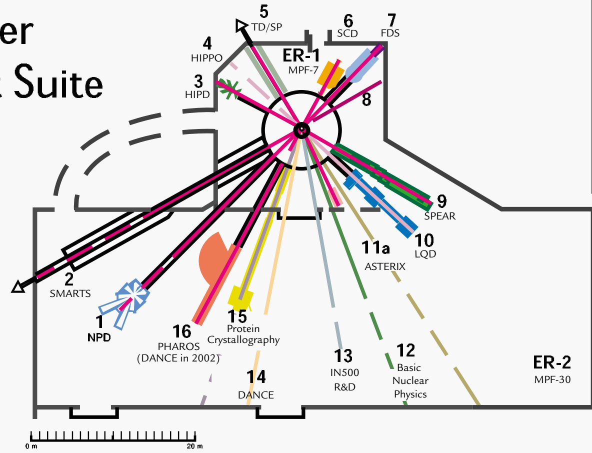
γ's from neutron capture detected by CsI(Tl) and photodiode detector array operating in current mode

gain provided by low-noise solid-state preamplifiers

run time: 3 $\times$ 2500 hours delivered, w/ 150 μA

Overview

Lujan Center Instrument Suite



Moderators
1, 2, 16: high-resolution H_2O decoupled
3, 4, 5: high-intensity H_2O decoupled
6, 7, 8: high-intensity H_2O decoupled
9, 10, 11: ℓH_2 @ 20 K partially coupled
12, 13: ℓH_2 @ 20 K coupled
14, 15: H_2O coupled

FP1 **Neutron Powder Diffractometer (NPD)** allows for studies of complex structures, internal strain measurements, and phase transformation.
Don Brown, 505-667-7904, dbrown@lanl.gov

FP2 **Spectrometer for Materials Research at emperature and Stress (SMAR S)** will allow measurements of spatially resolved strain-fields, phase deformation and load transfer in composites, the evolution of stress during temperature (or pressure) fabrication, and the development of strain during reactions (such as reduction, oxidation, or other phase transformations).
Mark Bourke, 505-665-1386, bourke@lanl.gov

FP3 **High Intensity Powder Diffractometer (HIPD)** is designed to study the atomic structure of materials that are available only in polycrystalline or noncrystalline forms.
Robert Von Dreele, 505-667-3630, vondreele@lanl.gov

FP4 **High-Pressure-Preferred Orientation (HIPPO)** instrument is a new high-intensity powder diffractometer for high-pressure and texture measurements.
Kristin Bennett, 505-665-4047, bennett@lanl.gov and Robert VonDreele, 505-667-3630, vondreele@lanl.gov

FP5 **FP5** is used to study the Doppler shift and broadening of low-energy nuclear resonances in materials under extreme conditions and for structural studies using transmission Bragg diffraction.
Vincent Yuan, 505-667-3939, vyuan@lanl.gov

FP6 **Single Crystal Diffractometer (SCD)** has been used to study the structure of organometallic molecules, unique binding of H_2 crystal structure changes at solid-solid-phase transitions, magnetic spin structures, twinned or multiple crystals, and texture.
Yusheng Zhao, 505-667-3886, yzhao@lanl.gov

FP7 **Filter Difference Spectrometer (FDS)** is designed to determine energy transferred to vibrational modes in a sample by measuring the changes in the energies of the scattered neutrons.
Juergen Eckert, 505-665-2374, juergen@lanl.gov

FP9 **Surface Profile Analysis Reflectometer (SPEAR)** is used with an unpolarized neutron beam to study solid/solid, solid/liquid, solid/gas, and liquid/gas interfaces.
Greg Smith, 505-665-2842, gsmith@lanl.gov and Jaroslaw Majewski, 505-667-8840, jarek@lanl.gov

FP10 **Low-Q Diffractometer (LQD)** is designed to study structures with dimensions in the range from 10 to 1000 Å. It measures a broad Q-range in a single experiment without physical changes to the instrument.
Rex Hjelm, 505-665-2372, hjelm@lanl.gov

FP11a **AS ERIX** will provide a polarized neutron beam for studies of magnetic materials, using reflectometry and diffraction, and includes application of high magnetic fields.
Mike Fitzsimmons, 505-665-4045, fitz@lanl.gov

FP12 **FP12** will be used for a fundamental nuclear physics experiment to precisely measure the asymmetry of the emission of gamma rays from the capture of polarized neutrons by protons.
David Bowman, 505-667-7633, bowman@lanl.gov

FP13 **IN500** is a protoype instrument under development employing novel techniques to enhance inelastic cold-neutron spectroscopy at spallation neutron sources.
Margarita Russina, 505-667-8841, russina@lanl.gov
Ferenc Mezei, 505-667-7633, mezei@lanl.gov

FP14 **Detector for Advanced Neutron Capture Experiments (DANCE)** will be used for the study of neutron capture on radioactive nuclei in support of the stockpile stewardship program and for nuclear astrophysics.
John Ullmann, 505-667-2517, ullmann@lanl.gov

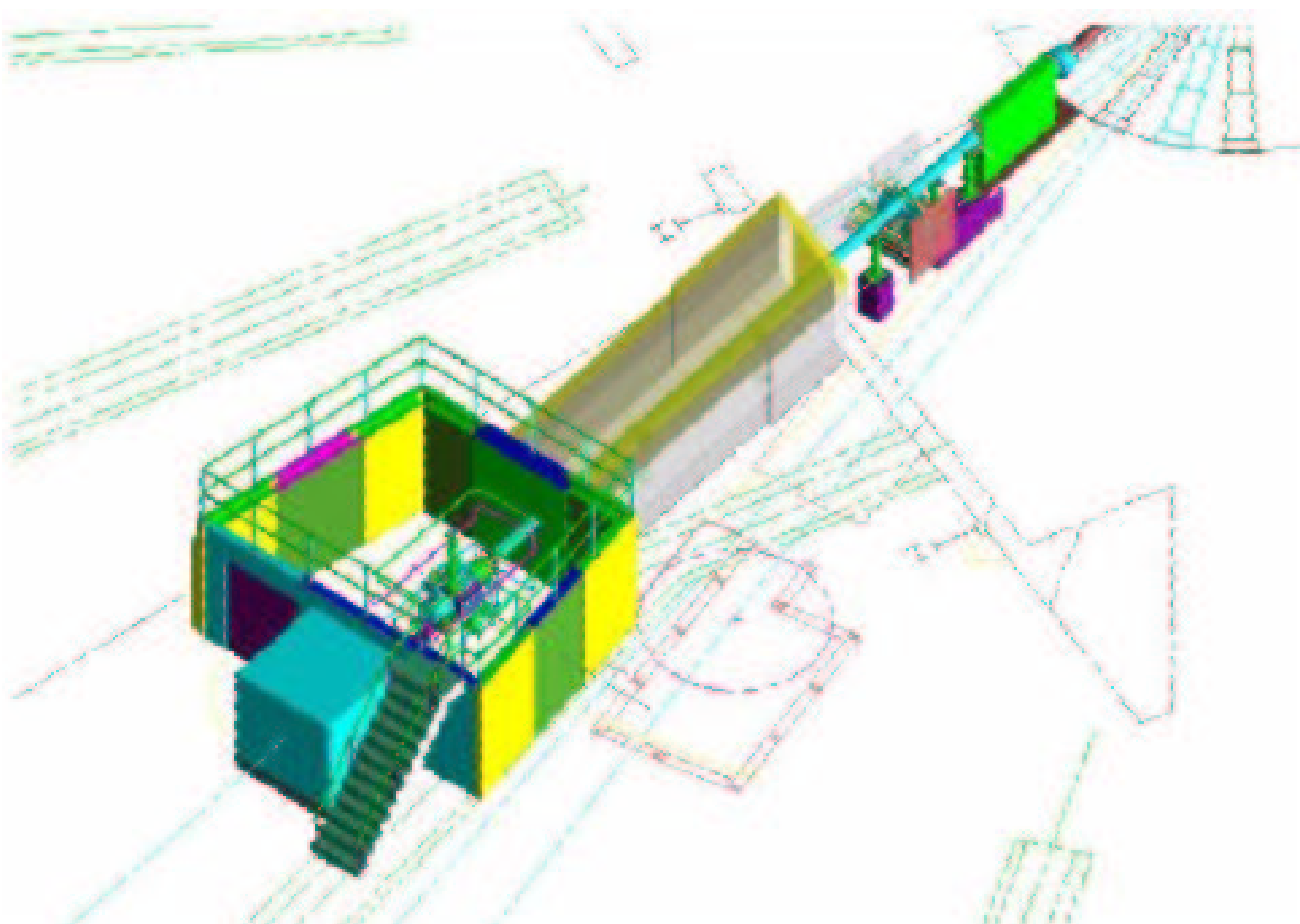
FP15 **Protein Crystallography Station (PCS)** is a single-crystal diffractometer designed for structure determinations of large biological molecules.
Paul Langan, 505-665-8125, langan_paul@lanl.gov
Benno Schoenborn, 505-665-2033, schoenborn@lanl.gov

FP16 **PHAROS** is a high-resolution chopper spectrometer designed for studies of Brillouin scattering, magnetic excitations, phonon densities of state, crystal-field levels, and chemical spectroscopy and measurements of S(Q,ω).
Robert McQueeney, 505-665-0841, mcqueeney@lanl.gov

NPDGamma building FP12 to be ready for:

commissioning run Fall 2002

production data taking 2003



(MOU between LANSCE and P Divisions)

Flight Path 12 Construction Progress

in-pile
guide

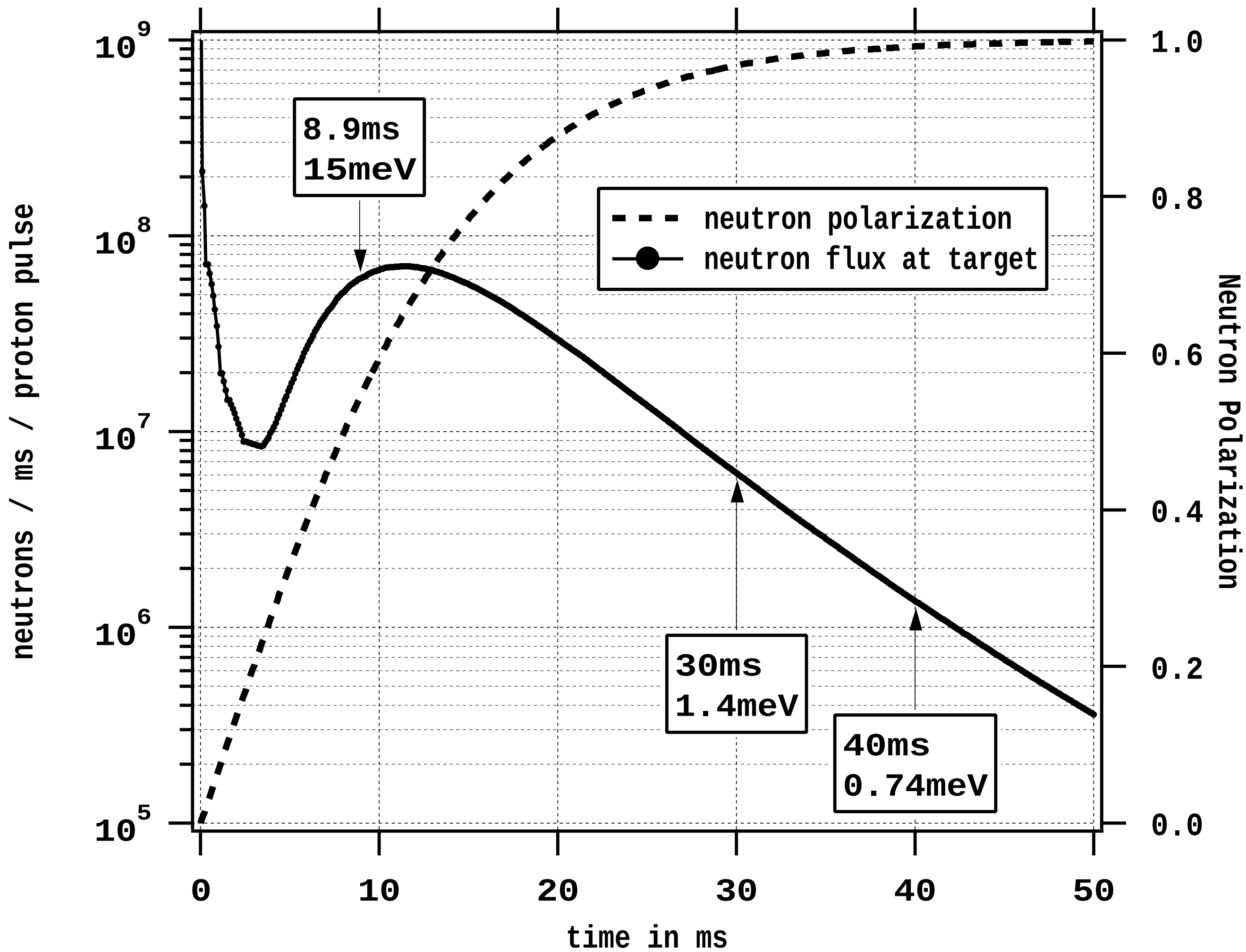
shutter

frame
overlap
chopper

Pulsed beam: time of flight $\longrightarrow$ energy

Use energies 1.5 meV to 15 meV

Monte Carlo calculation



> 15 meV:
no asymmetry due to ortho/para spin flip

< 1.5 meV:
very small flux, chopper near the moderator cuts these n to prevent frame overlap. So use this part of each pulse to monitor instrumental noise

PV asymmetry A_γ is independent of energy

NPDGamma Test Runs: Fall 2000, Fall 2001

Lujan Center FP11A

- measured n flux to benchmark Monte Carlo

- verified n intensity fluctuations to be small

- polarized a neutron beam with a ^{3}He spin filter (thickness 6 atm·cm, $P \approx 26.5\%$)

- measured RF spin flipper efficiency ($> 95\%$) vs. energy and position

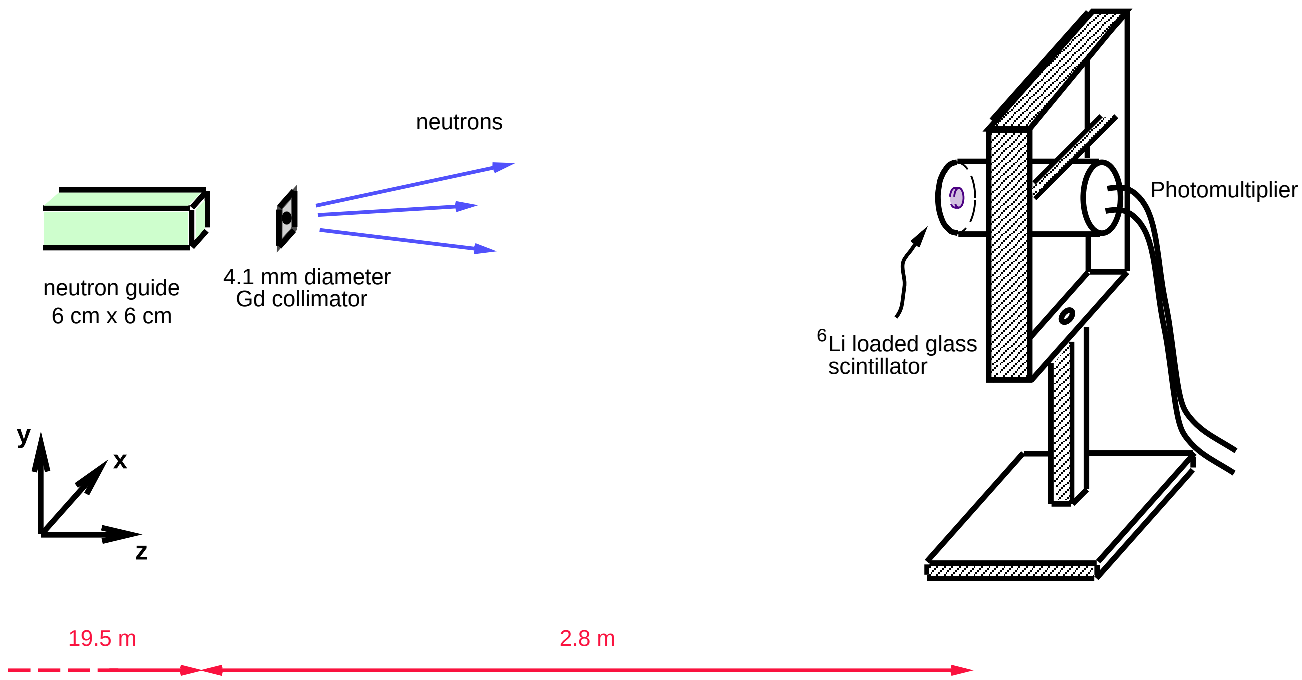
- used a new transmission back monitor (^{3}He/H_2) to observe beam intensity and measure RF spin flipper performance

- measured PV neutron capture asymmetries in Cl, La, Cd, to $\pm 2.5 \times 10^{-6}$ (stat.), $\pm$few $\times 10^{-7}$ (syst.) in eight hours data taking per target, using four CsI(Tl) current mode γ detectors and 3" vacuum photodiodes, low-noise solid-state preamplifiers, and VME-based DAQ system

- tested detector alignment schemes

Neutron Flux Measurement (FP11A, Fall 2000)

Measured the flux by collimating the beam and counting with a small detector on a movable stage



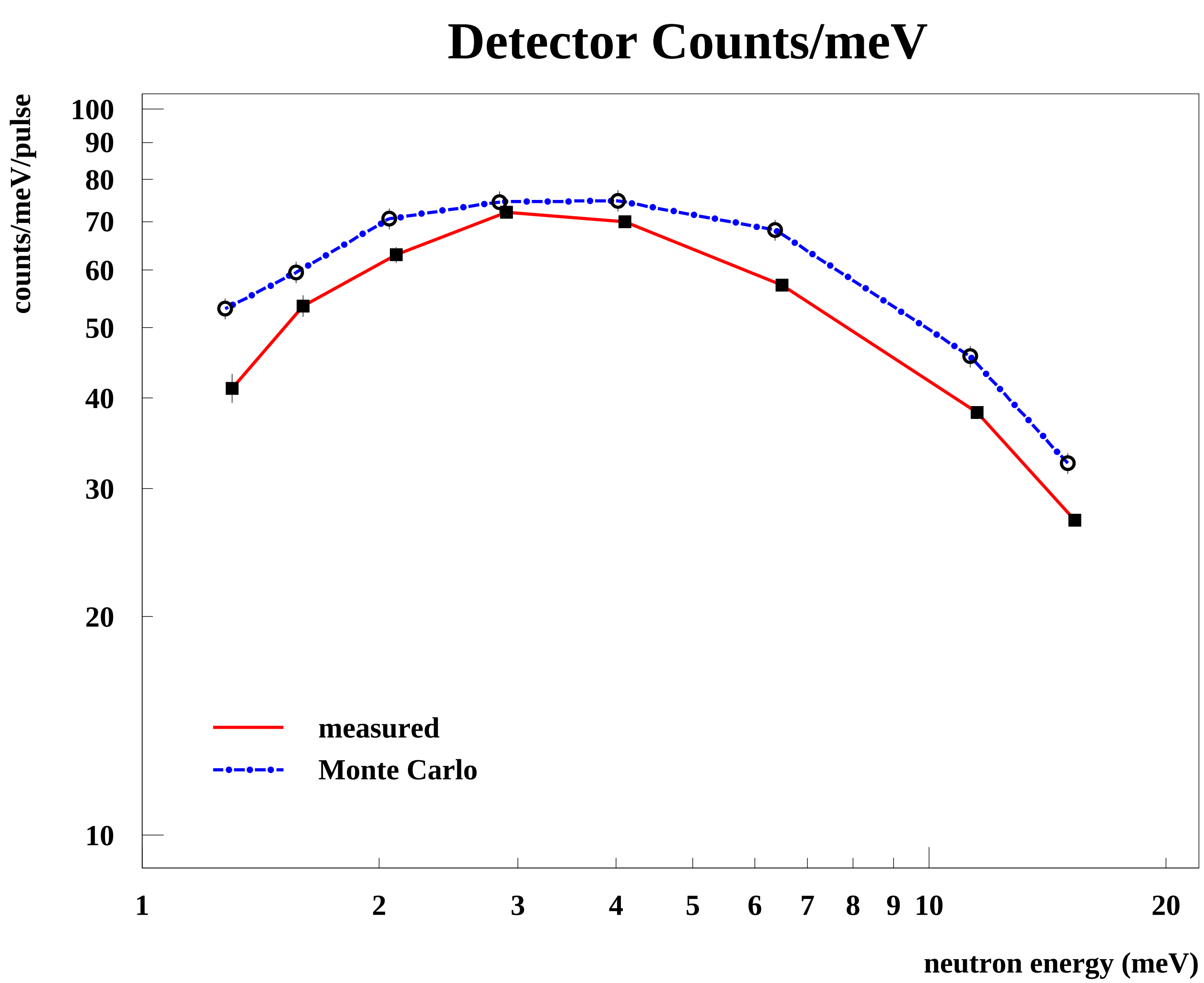
$$n + {}^6\mathrm{Li} \rightarrow {}^4\mathrm{He} + {}^3\mathrm{H} + 4.78\ \mathrm{MeV}$$

$$\sigma(\mathrm{b}) = 149/\sqrt{\mathrm{E(eV)}}$$

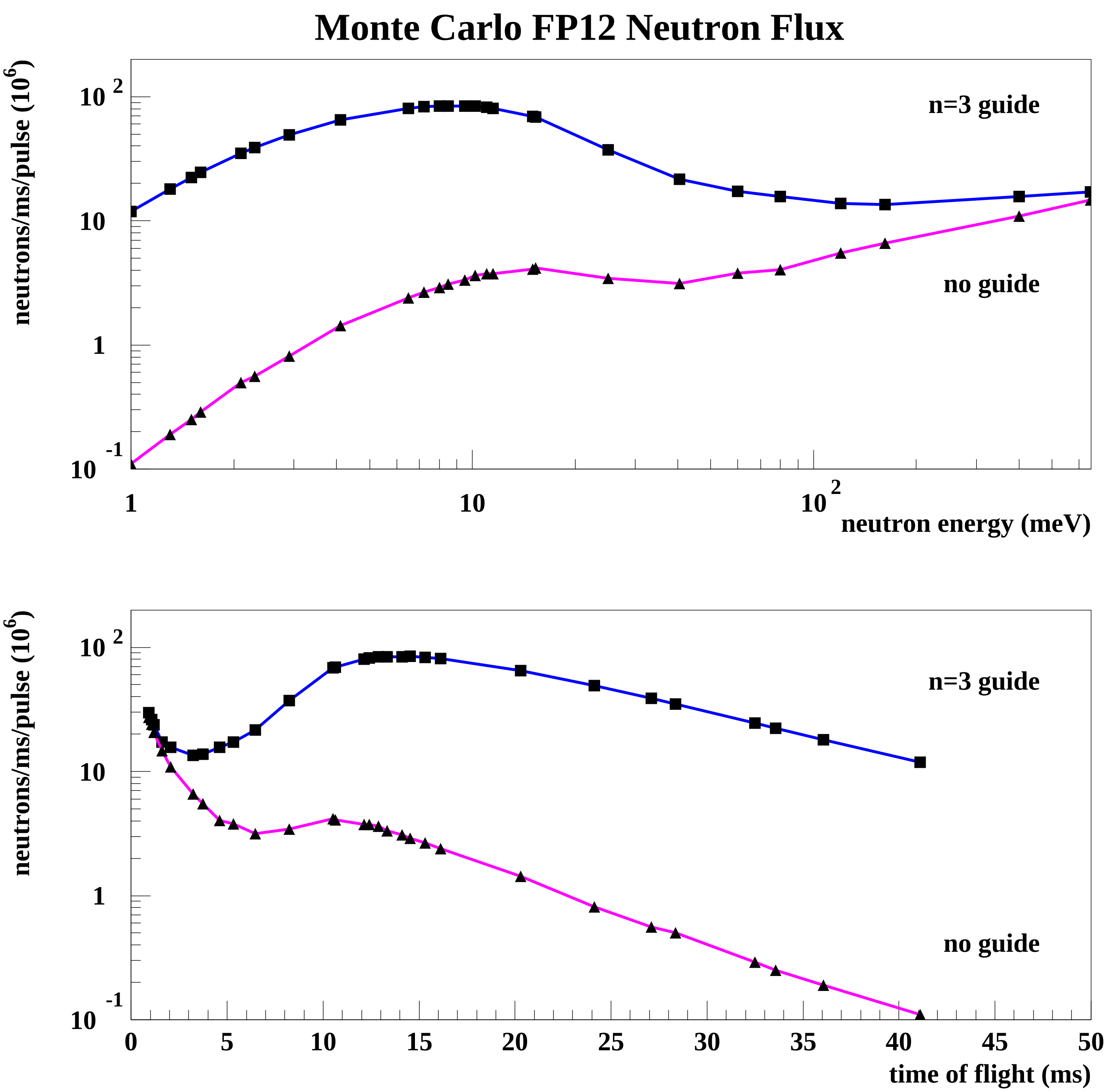
Neutron Flux Measurement (FP11A, Fall 2000)

Compare measured flux to predicted flux for a partially coupled LH_2 moderator, using a Monte Carlo to calculate neutron guide transport and collimation effects for FP11A

Excellent agreement (20%)
with magnitude and E dependence



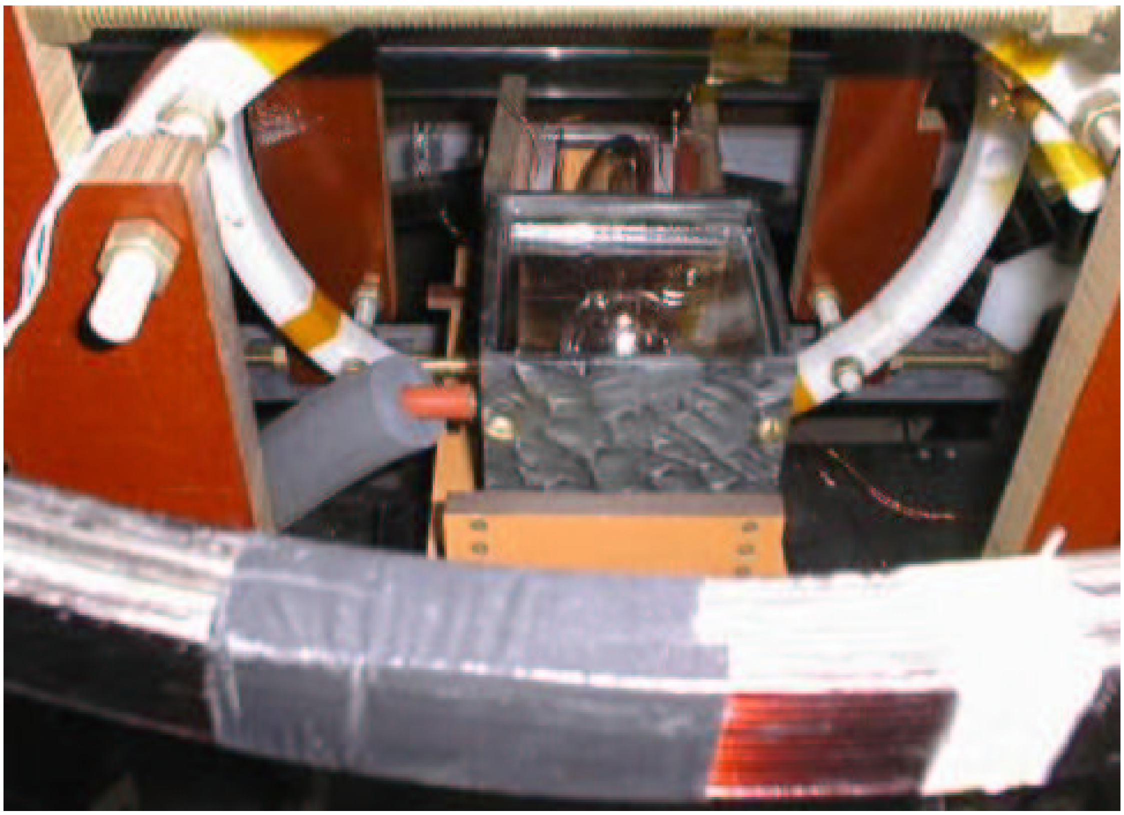
Flux of neutrons out of the $m = 3$ guide



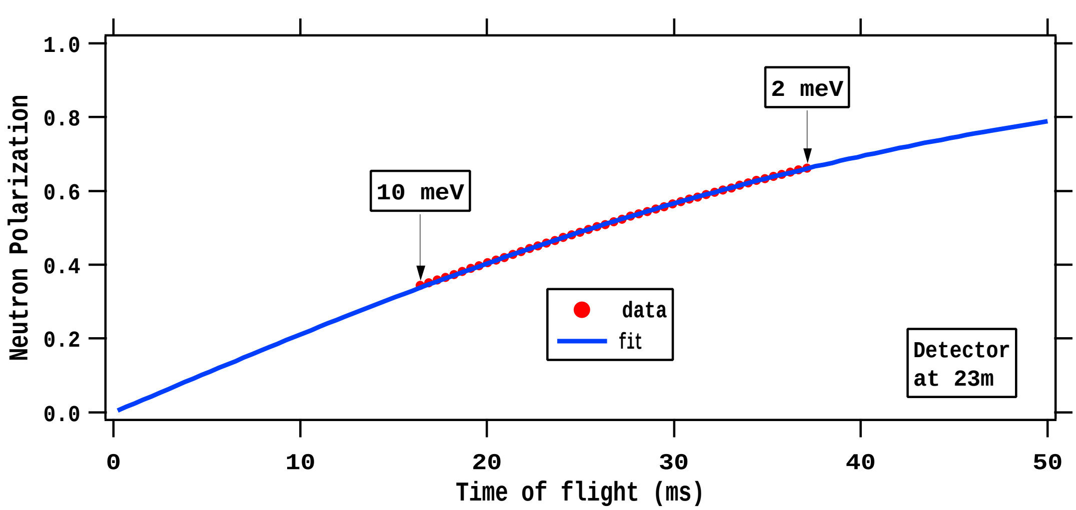
^{3}He Spin Filter

Optical pumping of Rb vapor, which polarizes ^{3}He by hyperfine spin-exchange collisions.

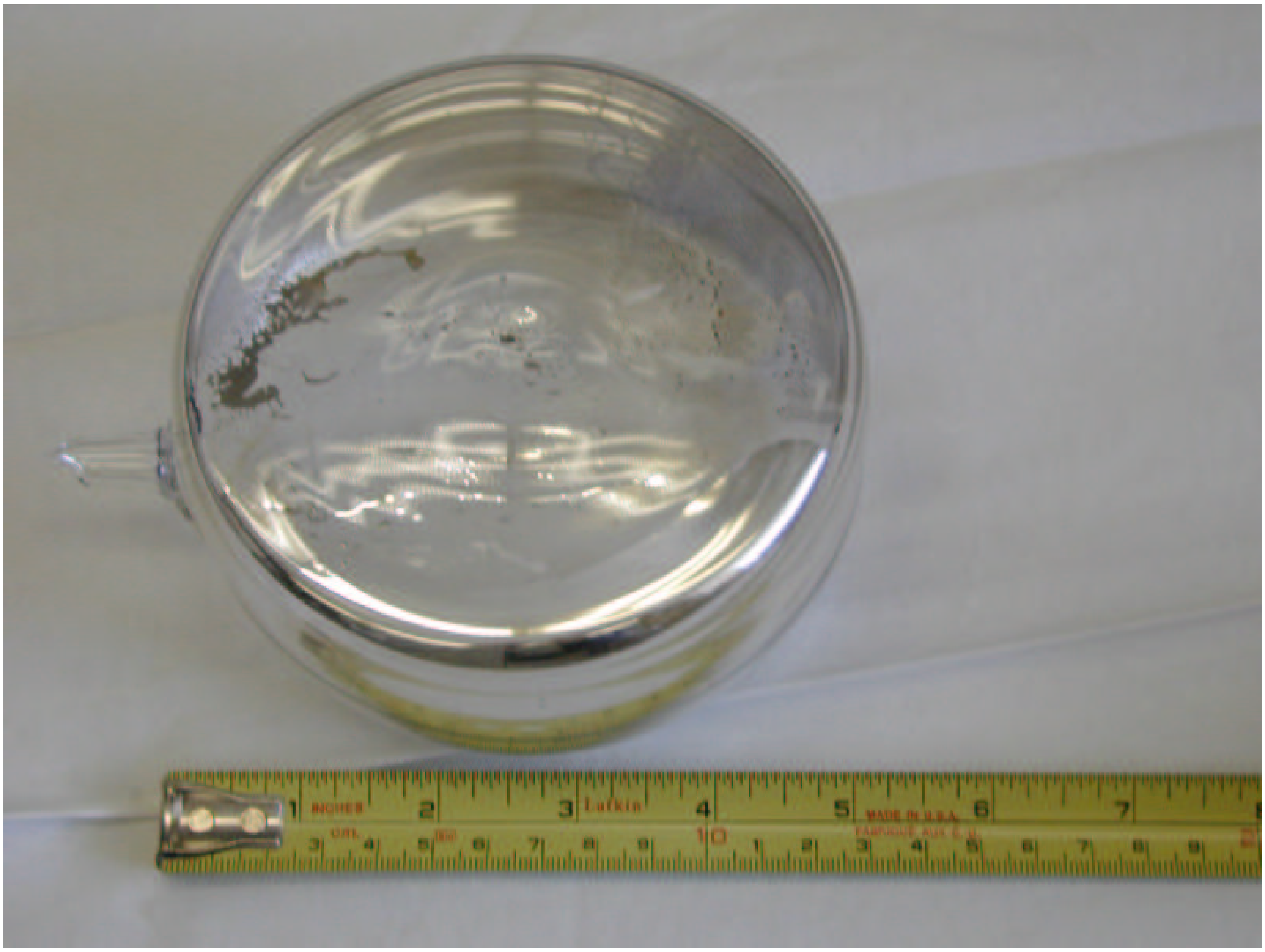
Neutron beam is polarized by passing through the cell. Antiparallel spin neutrons are absorbed.



Fall 2000 Test Run: ^{3}He polarization of 26.5% $\longrightarrow n$ polarization of 30-70% for 2-10 meV

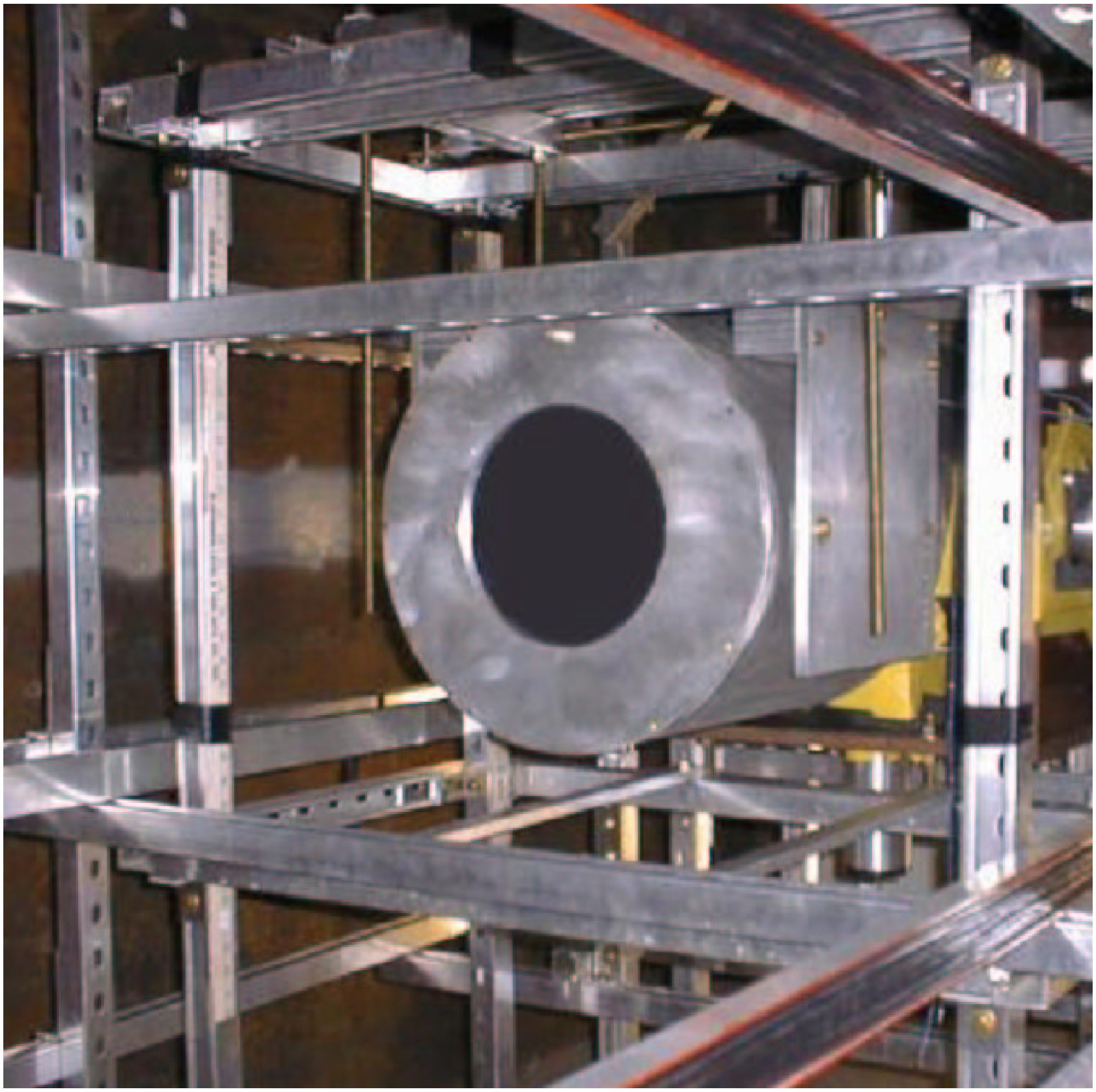


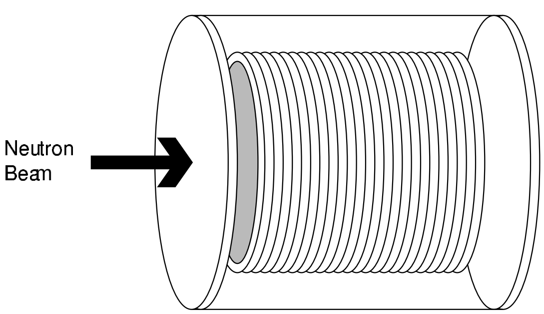
^{3}He Spin Filter

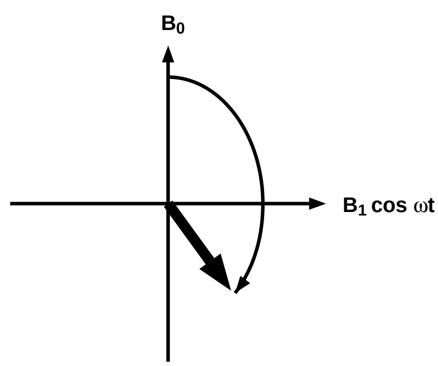


NIST group has fabricated a large single cell:
12 cm dia., $T_1 > 500$ hr $\rightarrow$ 50% ^{3}He pol.

Radio Frequency Spin Flipper



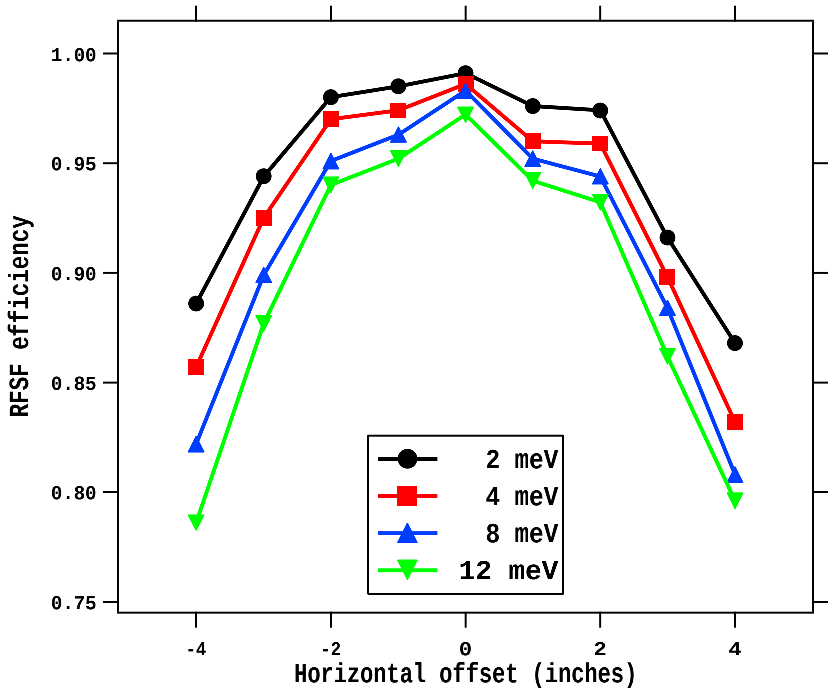


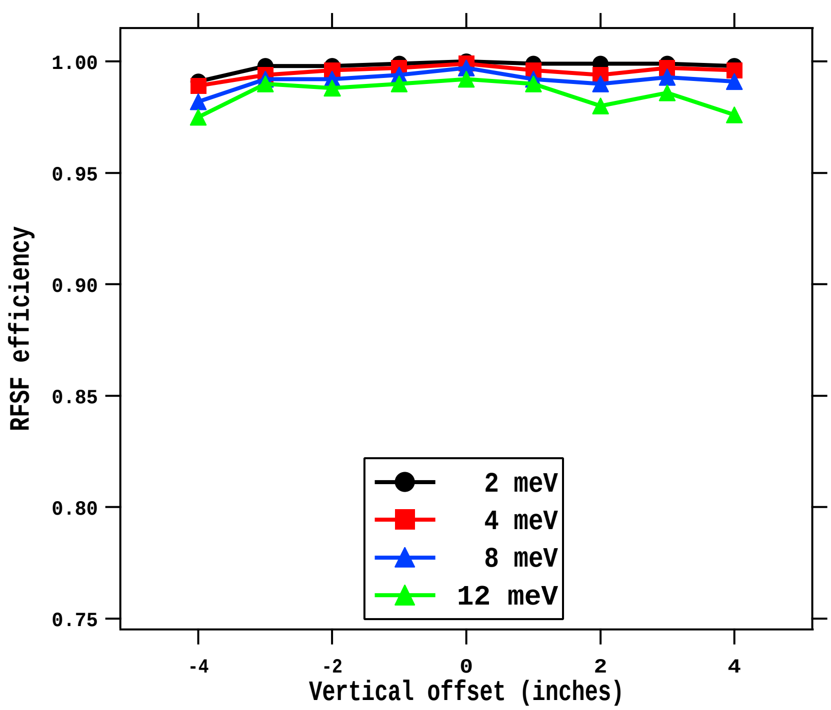


In a DC magnetic field, apply a resonant RF magnetic field to precess the neutron spin by π

30 kHz field, amplitude $\sim 1/(t.o.f.)$

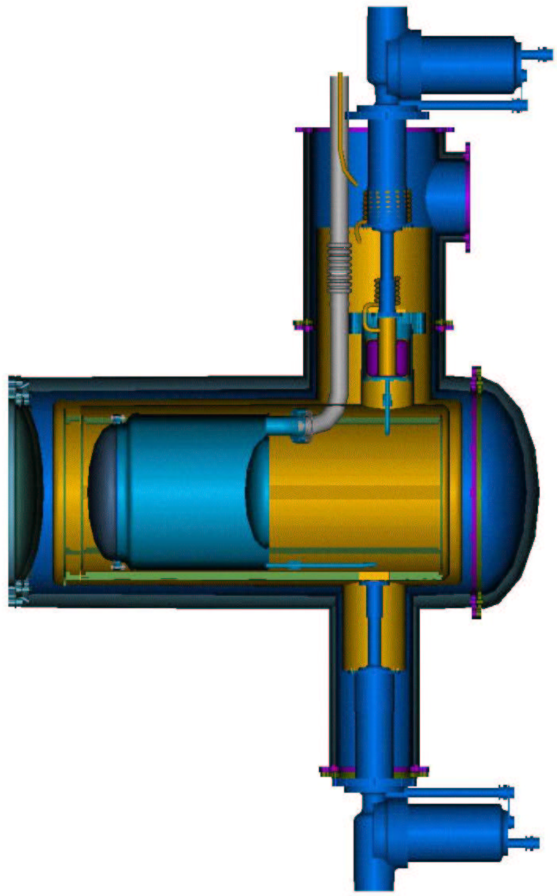
Spin flipper efficiency versus position
very good (>95% on axis)





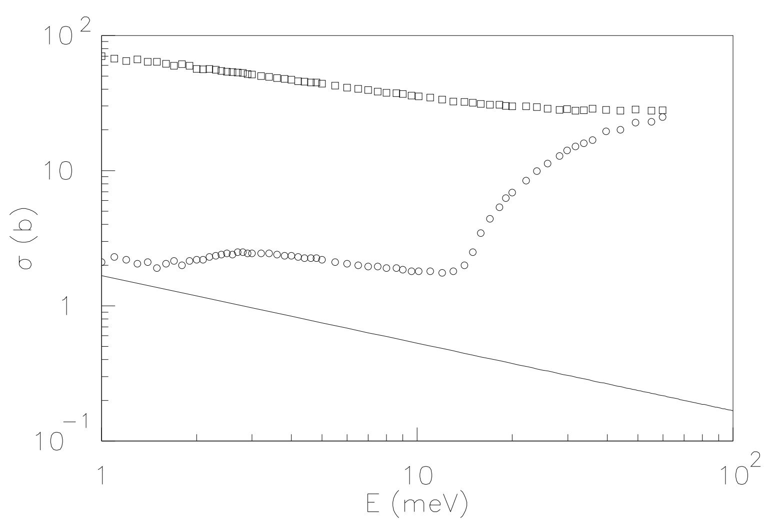
Liquid para-hydrogen target

20 ℓ, Mg-Al cryostat window, ^{6}Li liner



n cross-sections: ortho- ($\uparrow\uparrow$) and para- ($\downarrow\uparrow$) hydrogen

$\square$ ortho- scattering, $\circ$ para- scattering, $-$ np capture

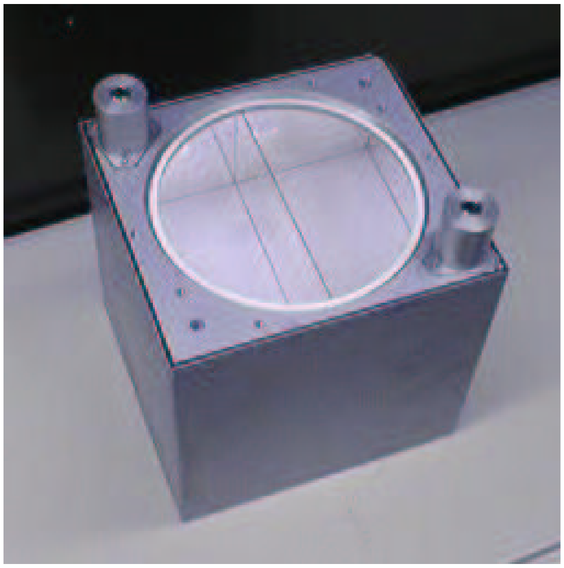


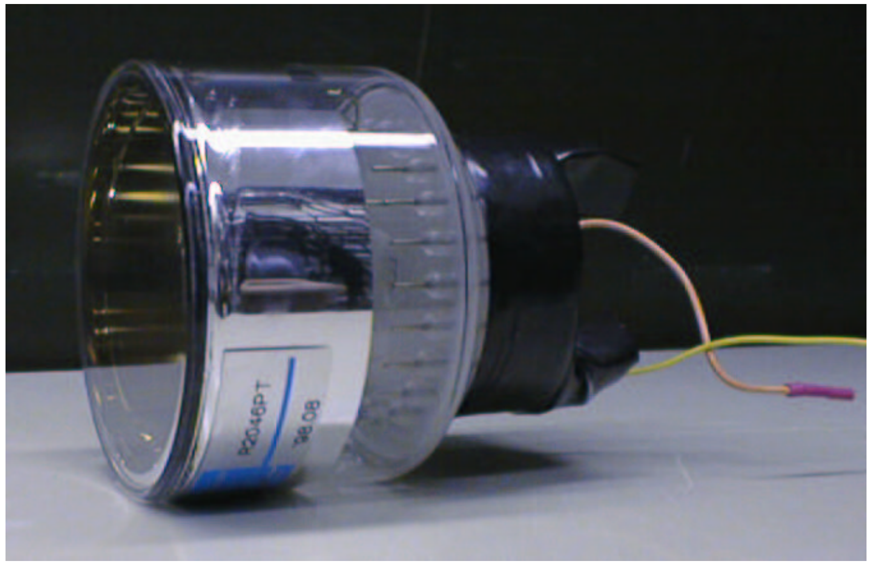
at 17K, ortho- fraction is 0.03%

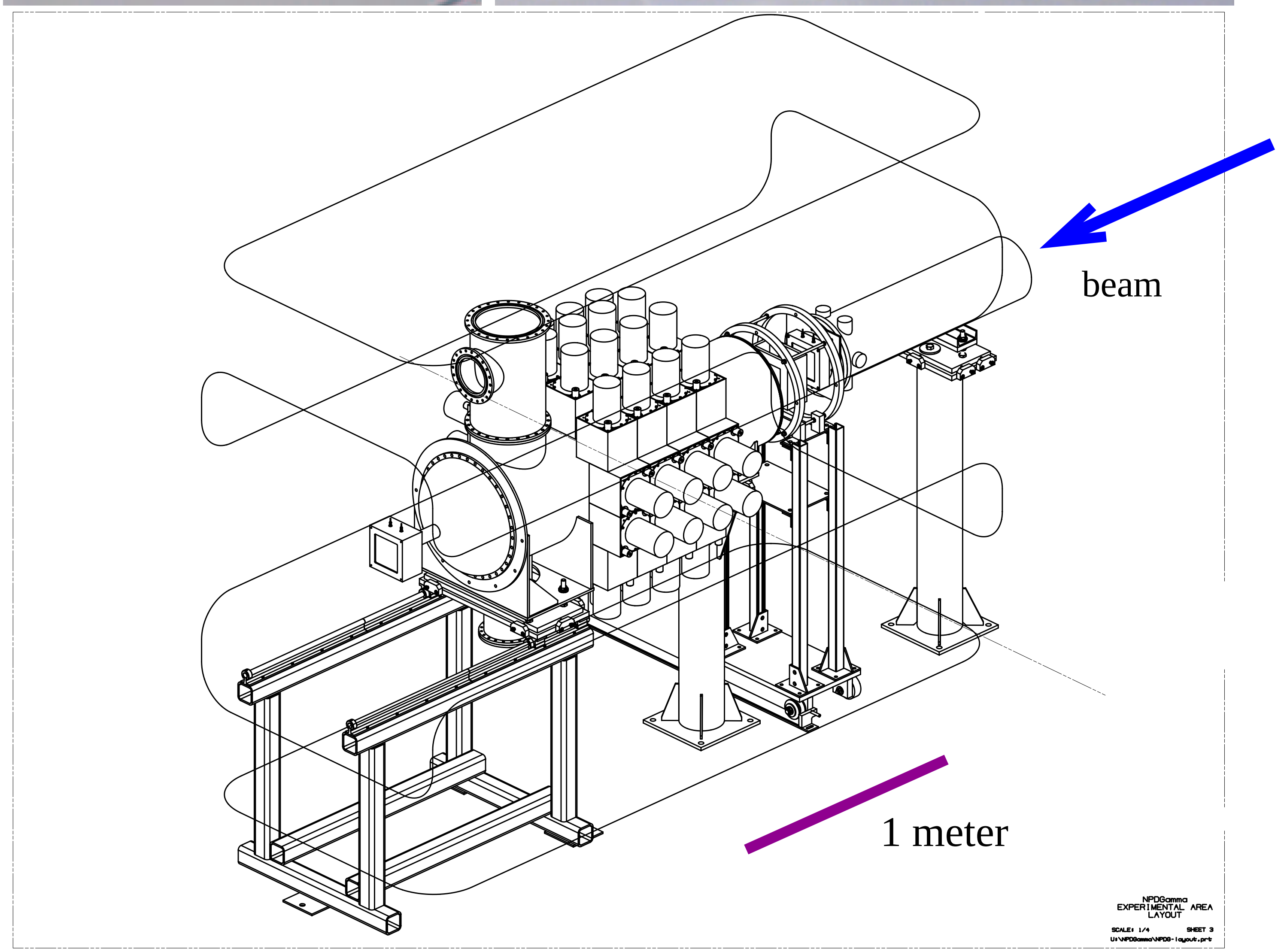
Para-hydrogen: necessary to allow neutron capture and to preserve neutron polarization upon scattering

CsI(Tl) and Photodiode γ Detectors

48 detectors in the full array







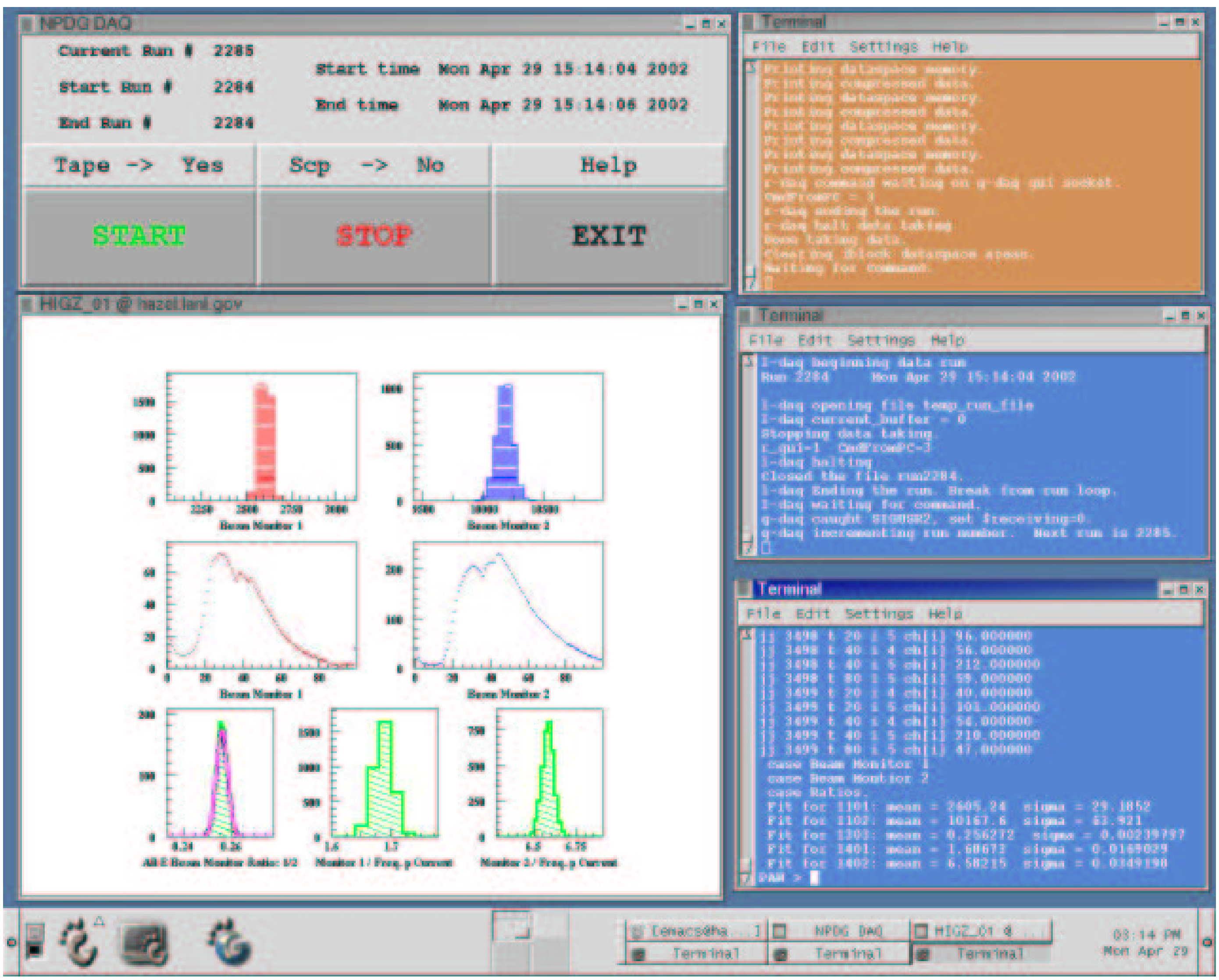
(Neutron polarization direction up-down.)

Data Acquisition System

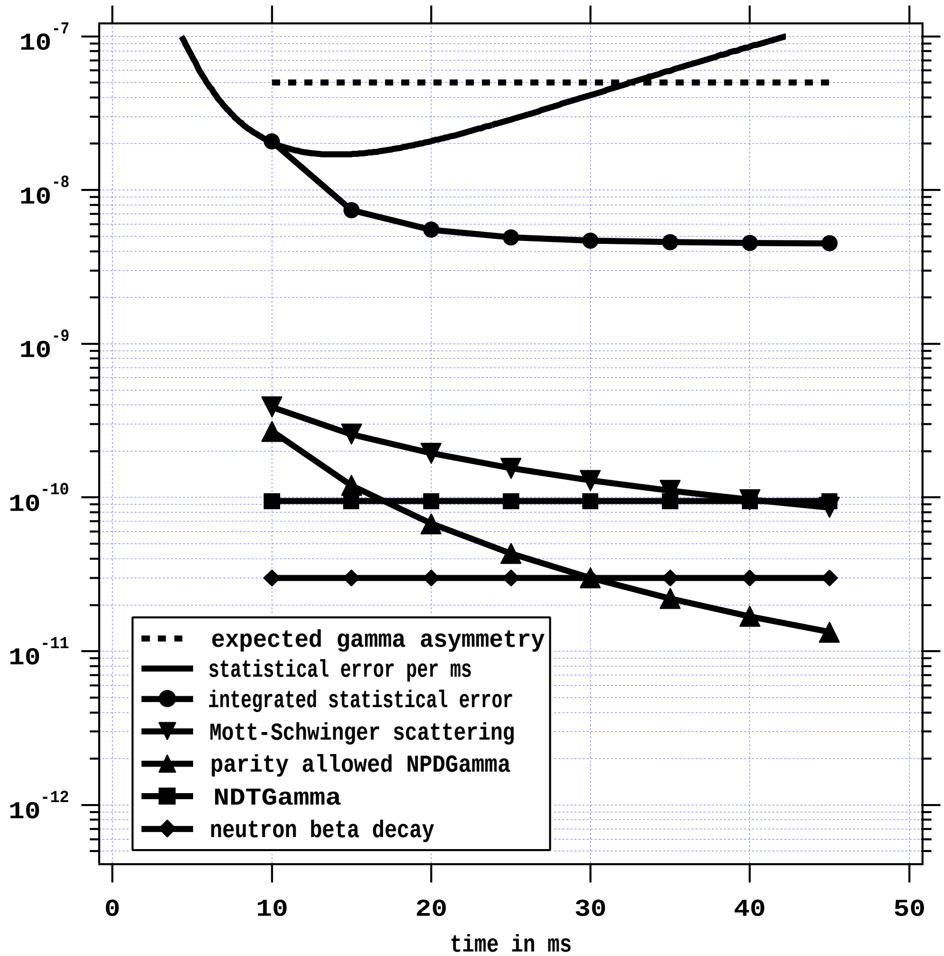
VME/Linux system

96 channels of 16-bit,

100 kHz sampling ADC's



NPDGamma Systematic Errors



Physics processes:

- activated materials (e. g. cryostat windows) emit γs in β-decay
- Stern-Gerlach steering
- L-R asymmetries:
  $n-p$ elastic scattering
  $n-p$ parity-allowed γ asymmetry
  Mott-Schwinger scattering (n spin-orbit interaction)

Instrumental issues: electronic noise, sensitivity to magnetic fields, gain stability over time

Null tests of E $>$ 15 meV and at end of each pulse

Systematic Errors: Stern-Gerlach Effect

A vertical magnetic field gradient causes spin-up neutrons to be deflected one way, spin-down the other, creating a false up-down asymmetry.

$$\text{Stern-Gerlach force} = \vec{\mu} \cdot \nabla B$$
$$F_z = -(\partial B_z/\partial z)\, \mu_{\text{neutron}}\, g\, m_s$$

$$\begin{aligned}\mu_{\text{neutron}} &= -1.913\, \mu_N \\ &= -1.913 \times 3.15 \times 10^{-14} \text{ MeV/T} = 1 \times 10^{-30} \text{J/G}\end{aligned}$$

Taking $g\, m_s = 2 \times 1/2 = 1$, and the design limit on field gradients $(\partial B_z/\partial z) < 1$ mG/cm $= 0.1$ G/m, the force is

$$F_z = 1 \times 10^{-31} \text{ N}.$$

The distance the centroid of the beam is deflected is

$$d = 1/2at^2 = 1/2(F_z/m)t^2,$$

where m is the neutron mass, t is the time spent in transit of the field gradient. The distance between the polarizer and the LH_2 target is 1 m, which is traversed by a 1 meV neutron in $\sim$2 ms.

The displacement is

$$d = 1/2 \times (10^{-31} \text{ N}/1.67 \times 10^{-27} \text{ kg}) \times (0.002 \text{ s})^2$$

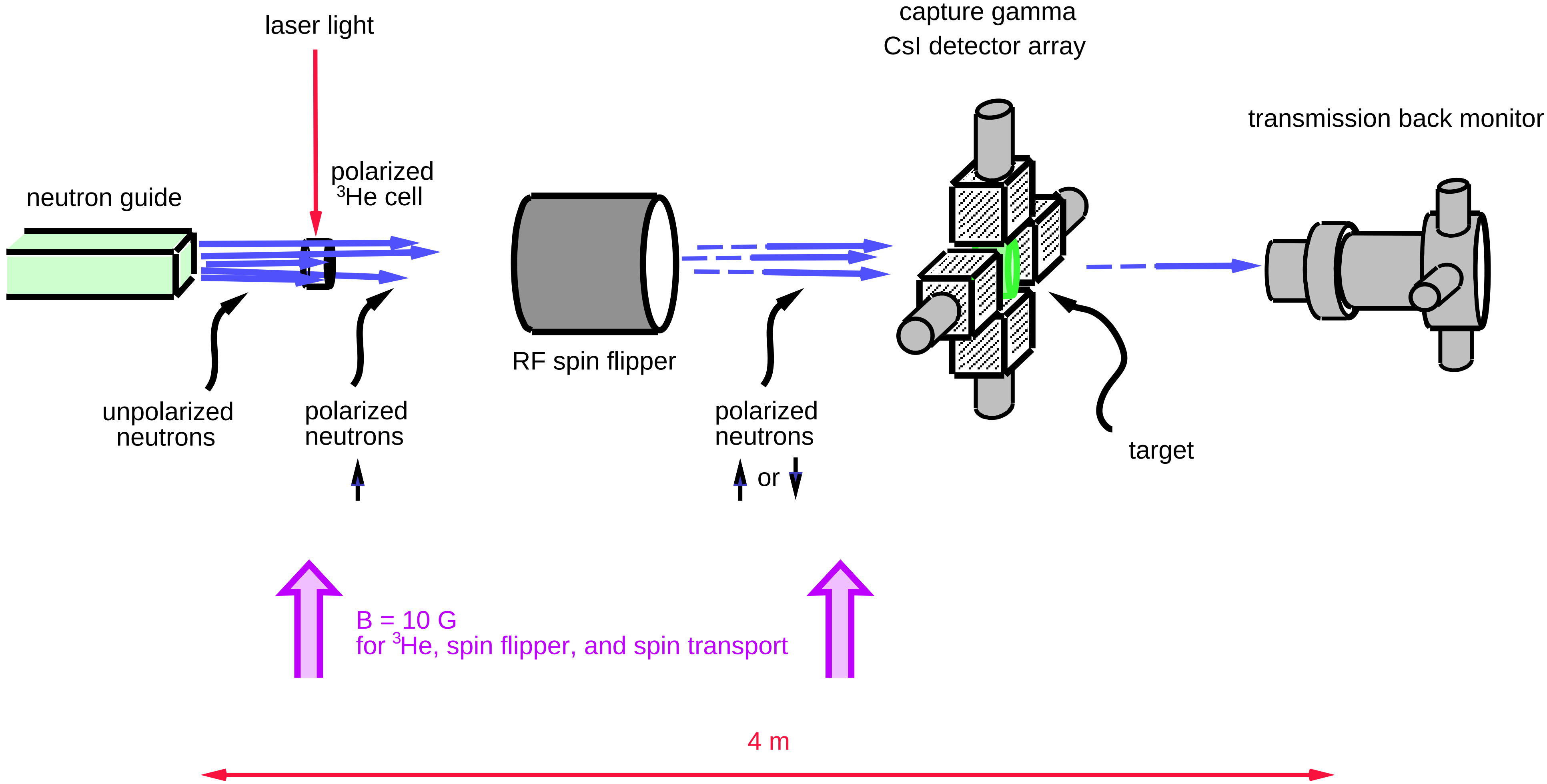
$$= 1 \times 10^{-10} \text{ m}.$$

False asymmetry: assuming rate goes as solid angle (r^2), and $r \gg d$, r=0.3 m, $A_{false} = [(r+d)^2 - (r-d)^2]/(sum)$,

$$A_{false} = 2d/r = 7 \times 10^{-10}.$$

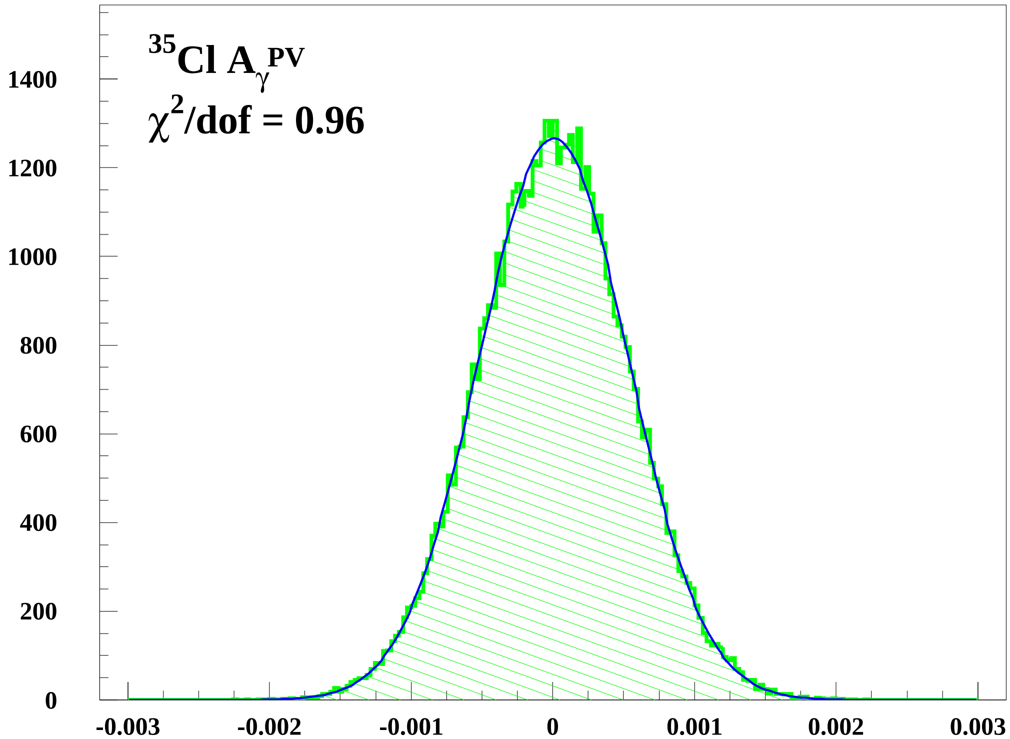
Spin flips used to reduce this effect.

Fall 2000 Engineering Run Setup



Asymmetry measurements on Cl, La, Cd

up/down $\rightarrow$ parity violating



Raw PV Asymmetries ($\times 10^{-6}$)

^{35}Cl	-7.68 ± 2.17
^{139}La	-5.88 ± 2.35
^{113}Cd	$+1.94 \pm 1.48$

Physics Asymmetries A_γ ($\times 10^{-6}$)

	^{35}Cl	^{113}Cd	^{139}La
Leningrad	-27.8 ± 4.9	-1.3 ± 1.4	-17.8 ± 2.2
ILL	-21.2 ± 1.7	-	-
LANSCE	-23.1 ± 6.5	$+5.8 \pm 4.4$	-17.1 ± 6.8

(LANSCE results to be published.)

Test Run error scaling to NPDGamma

	Test Run	Full Expt.
run time	8 hrs	7500 hrs
detectors	4	48
proton I	90 μA	150 μA
moderator Φ	1	1.5
guide m	1	3
guide size	6×6 cm	9.5×9.5 cm
σ_A	2.5×10^{-6}	5×10^{-9}

NPDGamma Schedule

to June 2002	Beamline through ER1 &
	integrated shielding installed
November 2002	Commission beamline through ER1
February 2003	Installation of ER2 guide complete
June 2003	FP12 Commissioning Run
August 2003	Commission entire experiment
Fall 2003	Begin data taking
December 2003	Data match existing stat. precision on H_π^1
2004 / 2005	Continue data taking for 10% measurement

NPDGamma Status

- FP12 flight path is under construction.

- Experiment is under construction.
  10% scale apparatus tested Fall 2000.
  Alignment scheme & monitors tested Fall 2001.
  All crucial components demonstrated.

- Test runs indicate all components are sufficient for target A_γ experimental error, 0.5×10^{-8}.

- Potential systematic errors studied extensively.

- NPDGamma will make a clean measurement of H_π^1, the most fundamental weak N-N coupling.